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Environmental Aspects of Commercial Radioactive Waste Management

Volume 2 of 3

May 1979

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Vol-2

Environmental Aspects of Commercial Radioactive Waste Management.

Volume 2 ~~of 3~~

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6.1 REFERENCE MIXED-OXIDE FUEL FABRICATION PLANT

6. ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT ASSOCIATED WITH LWR FUEL REPROCESSING – MIXED-OXIDE FUEL FABRICATION PLANT

A mixed-oxide fuel fabrication plant (MOX FFP) prepares fuel containing a mixture of uranium oxide (UO_2) and plutonium oxide (PuO_2) for recycle to a reactor; about 5% of the heavy metal content is plutonium. The capacity of the reference plant is 400 MTHM/yr. The major process steps involved in fuel preparation include mixing uranium oxide and plutonium oxide powders; preparing dense fuel pellets from the mixture by pressing, sintering, and grinding; sealing the pellets within Zircaloy cladding to form fuel elements; and recycling scrap. Figure 6.1.1-1 is a simplified schematic of these steps. These processes generate airborne, liquid, and solid wastes that must be disposed of in an environmentally acceptable manner.

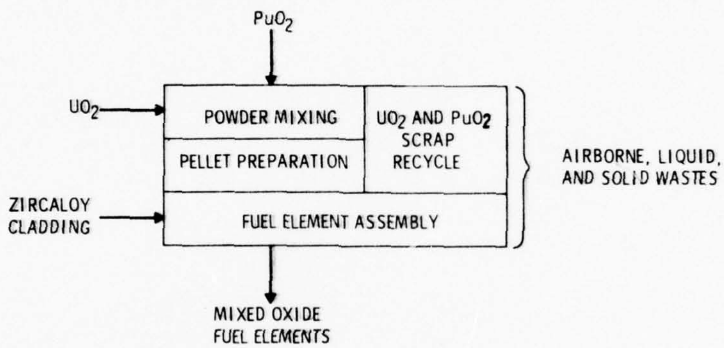


FIGURE 6.1.1-1. Simplified Schematic of the Mixed-Oxide Fuel Fabrication Plant Process

6.1 REFERENCE MIXED-OXIDE FUEL FABRICATION PLANT* (DOE/ET - 0028 Sec. 3.2.4)

The reference plant is built on a 400-ha site, the perimeter of which is fenced with posted agricultural-type fencing. The main processing facilities are located near the center of the site within a protected security area of about 6 ha. These facilities include uranium oxide and plutonium oxide receiving areas, a fuel rod production building, a fuel rod finishing and shipping building, and a waste treatment area.

The principal point for releasing airborne radioactive materials is a 20-m-high exhaust stack. The flow rate at this stack is 15 m^3/sec at a linear velocity of 15 m/sec.

About 1.1 x 10^8 MJ/yr of heat are rejected to the atmosphere via a cooling tower. Cooling tower characteristics of importance to environmental assessment are as follows:

Water flow	
Circulating	62 ℓ/sec at 27 to 38°C
Evaporated	1.2 ℓ/sec at 38°C
In drift	0.006 ℓ/sec at 38°C
In blowdown	0.22 ℓ/sec at 27°C
Makeup	1.4 ℓ/sec at 10°C

* Since the MOX-FFP is a production facility, environmental analysis of its operation is not within the scope of this report and only those aspects that are necessary to develop the environmental aspects of waste management are presented.

6.2 WASTE TREATMENT

6.2 WASTE TREATMENT

At a mixed-oxide fuel fabrication plant (MOX FFP) liquid and solid radioactive wastes that require management are generated. Waste management facilities considered in this section include immobilization of wet wastes and particulate solids, failed equipment and noncombustible waste treatment, and general trash and combustible waste treatment. This section describes and compares environmental effects associated with alternative methods of managing these wastes.

Vaporized excess water is the major process off-gas stream from the MOX FFP. This stream is mixed with the large volume of building ventilation exhaust air and discharged up the stack. The only other source is off-gas from the contaminated scrap dissolver; this small stream is scrubbed to remove the bulk of the nitrogen oxides before it is mixed with the ventilation air stream for discharge. Since gaseous radioactive materials are not present in the MOX FFP, the gaseous effluent treatment system is designed solely to retain radioactive particulates.

6.2.1 Gaseous Effluents Released from the Excess Water Evaporator

The evaporation process is used to concentrate a solution or slurry by applying heat to drive off solvent vapors. This process has wide application in the nuclear industry for reducing waste volumes and the quantity of radionuclides in liquid effluents. Evaporation is usually used for radioactive wastes that require a high degree of separation between volatile and nonvolatile components. It is also used for wastes that are not amenable to treatment by less costly low-temperature operations such as precipitation, filtration, and ion exchange. Radioactive aerosols are generated during the process of evaporation.

Several types of evaporation equipment are commercially available. The simplest type is a vessel that contains the liquid to be evaporated and is equipped with a heat transfer device, such as a steam coil or jacket, for batch operation. Other evaporators are designed for continuous rather than batch operation. In these evaporators liquid is circulated through a heat exchanger in which condensing steam is the normal heat source. A typical natural circulation evaporator is equipped with a vertical shell-and-tube heat exchanger in which liquid circulation is induced by vapor formation within the tubes. Alternatively, a pump can be used for forced liquid circulation.

6.2.1.1 Environmental Effects Related to Facility Construction

Effects of constructing the excess water evaporation facility are included as an indistinguishable part of MOX FFP construction. Therefore, effects on the environment and natural resources cannot be segregated from effects related to MOX FFP construction.

6.2.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources and manpower required during operation of the excess water evaporator are included in those for operation of the MOX FFP.

Process Effluents. The amounts of radionuclides that reach the biosphere from the excess water evaporator are shown in Table 6.2.1-1. These radionuclides will contribute at least 1% to the total dose to a given organ from any pathway to man.

No nonradioactive pollutants will be released to the biosphere during planned operation of the excess water evaporator. Waste heat generated during evaporation processes is included in overall MOX FFP operation effects.

TABLE 6.2.1-1. Radionuclides Released to the Biosphere by the Excess Water Evaporator at the MOX FFP

Radionuclide	Quantity, Ci/yr
^{237}U	6×10^{-8}
^{238}Pu	7.6×10^{-5}
^{239}Pu	5.2×10^{-6}
^{240}Pu	1×10^{-5}
^{241}Pu	2.3×10^{-3}
^{241}Am	3.8×10^{-6}

Physical, Chemical, and Thermal Effects. All liquid and solid waste disposal for the excess water evaporator is part of the overall MOX FFP operation. Water vapor will be discharged through the MOX FFP atmospheric protection system stack at the rate of 1.4 m^3/day. No significant effects are postulated for this small release of water vapor.

Radiological Effects. Doses to individuals in the vicinity of the facility were calculated based on the releases of radionuclides listed in Table 6.2.1-1; exposure pathways, demography, and other parameters described for the reference environment (Appendix A); and mathematical models relating dose to man from radionuclide releases (Appendix B). The only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.2.1-2. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 6.2.1-3 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with <0.001 man-rem received from process sources as given in Table 6.2.1-4.

The annual total-body dose to the work force associated with the facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 45 man-rem. Table 6.2.1-4 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 6.2.1-2. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the Excess Water Evaporation Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
Air submersion	1.9×10^{-14}	1.9×10^{-14}	1.9×10^{-14}	1.9×10^{-14}	1.9×10^{-14}
Inhalation	3.7×10^{-8}			2.2×10^{-6}	8.7×10^{-7}
Ingestion	9.6×10^{-12}				4.1×10^{-10}
Total	3.7×10^{-8}	1.9×10^{-14}	1.9×10^{-14}	2.2×10^{-6}	8.7×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. After 30 years of release and accumulation in the environment.

b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.2.1-3. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Excess Water Evaporation Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	5.0×10^{-10}	5.0×10^{-10}	5.0×10^{-10}	5.0×10^{-10}
Inhalation	9.6×10^{-4}		5.7×10^{-2}	2.2×10^{-2}
Ingestion	1.1×10^{-7}			4.5×10^{-6}
Total	9.6×10^{-4}	5.0×10^{-10}	5.7×10^{-2}	2.2×10^{-2}

a. After 30 years of release and accumulation in the environment.

TABLE 6.2.1-4. Summary of Annual Total-Body Doses Received from Operation of the Excess Water Evaporation Facility and from Naturally Occurring Sources

	Dose, man-rem
Excess water evaporation facility	
Process work force (30 yr)	45
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.2.1-5 and 6.2.1-6 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.2.1-7. For perspective, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, compared with 0.6 man-rem received from the excess water evaporation facility.

TABLE 6.2.1-5. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released by the Excess Water Evaporation Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	5.9×10^{-13}	5.8×10^{-13}	5.8×10^{-13}	5.8×10^{-13}
Inhalation	2.4×10^{-5}		1.3×10^{-4}	5.2×10^{-4}
Ingestion	1.8×10^{-8}			7.3×10^{-7}
Total	2.4×10^{-5}	5.8×10^{-13}	1.3×10^{-4}	5.2×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.2.1-6. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the Excess Water Evaporation Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.5×10^{-8}	1.5×10^{-8}	1.5×10^{-8}	1.5×10^{-8}
Inhalation	6.2×10^{-1}		3.2	1.3×10^{1}
Ingestion	2.0×10^{-4}			8.0×10^{-3}
Total	6.2×10^{-1}	1.5×10^{-8}	3.2	1.3×10^{1}

TABLE 6.2.1-7. Summary of 70-Year Total-Body Doses Received from Operation of the Excess Water Evaporation Facility and Naturally Occurring Sources

	Dose, man-rem
Excess water evaporation facility	
Process work force (30 yr)	1350
Population (within 80 km)	0.6
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. Ecological effects of operation of the excess water evaporation facility are included as an integral part of MOX FFP operation.

6.2.1.3 Environmental Effects Related to Postulated Accidents

No minor, moderate, or severe accidents were postulated within the design basis of the excess water evaporation facility. Non-design basis accidents were not considered.

6.2.2 Failed Equipment and Other Noncombustible Waste Treatment (DOE/ET-0028 Sec. 4.3.2)

Failed equipment and noncombustible waste are among the solid wastes produced during operation of a mixed-oxide fuel fabrication plant (MOX FFP). The generation of small items of noncombustible waste is generally routine and predictable in a nuclear facility. The failure of large items of radioactive process equipment is not routine, however, and can seriously affect operating schedules. Prompt treatment and replacement of such equipment, including equipment disassembly and packaging for early removal of the failed equipment from the processing area, is essential to plant efficiency.

6.2.2.1 Equipment Disassembly and Packaging

This treatment concept prepares MOX FFP failed equipment and noncombustible waste for shipment to interim storage or to a repository. The treatment usually involves decontamination, disassembly, and packaging of the material. Wastes generated at a MOX FFP consist principally of metals, glass, and mineral forms. Examples of these wastes include failed equipment, vent ducts, metal packaging material, discarded tools, and miscellaneous used items such as assault masks. Processing of similar wastes has been routine in government fuels reprocessing facilities. Alternative treatment concepts involve varying degrees of decontamination before disassembly (if needed) and packaging by remote or direct contact methods.

Failed equipment and noncombustible waste at a 400-MTHM/yr MOX FFP will be generated at a rate of 80 m^3/yr and 82 m^3/yr respectively. Treatment of these wastes at a MOX FFP is performed in multifunctional areas used for general facility maintenance and waste management. A flow diagram illustrating reference treatment procedures is shown in Figure 6.2.2-1. Table 6.2.2-1 gives outputs from this treatment concept.

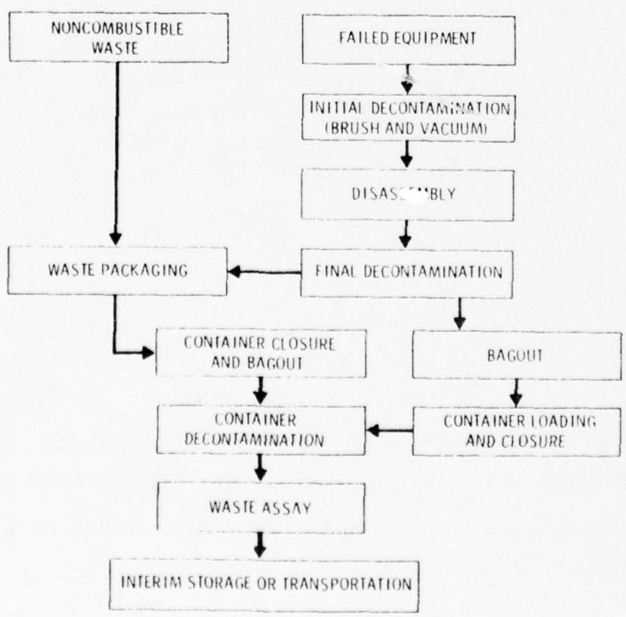


FIGURE 6.2.2-1. Flow Diagram for Treatment of MOX FFP Failed Equipment and Noncombustible Waste

TABLE 6.2.2-1. Annual Flow of Packaged Failed Equipment and Noncombustible Waste at a MOX FFP

Waste	55-gal Drums	Boxes[a]	Activity, Ci (Actinides)[b]
Low-level transuranic trash	394		24,000
Low-level transuranic equipment		20	2,400

a. Dimensions, 1.2 x 1.8 x 1.8 m.
b. ^{241}Pu, 95%; ^{238}Pu, 3%; ^{240}Pu, 0.4%; ^{239}Pu, 0.2%.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The equipment disassembly and packaging facility will be an integral part of the reference MOX FFP. Land use attributable to the disassembly and packaging facility is not separable from the overall land use requirements of the MOX FFP.

Water used during construction is estimated to be 800 m^3. Withdrawal of this amount of water from the R River is judged to be insignificant with respect to other downstream uses. During the construction period wells could probably supply the required amount of water without environmental consequence.

Materials committed for construction of the equipment disassembly and packaging facility are:

Concrete, m^3	610
Steel, MT	180
Copper, MT	1
Lumber, m^3	47

Energy resources committed for construction are:

Propane, m^3	4
Diesel fuel, m^3	38
Gasoline, m^3	38
Electricity	
Peak demand, kW	80
Total consumption, kWh	25,000

Manpower requirements for construction of the equipment disassembly and packaging facility amount to 15 man-yr, which will likely be integrated with labor schedules for the MOX FFP.

No additional transportation requirements have been identified beyond those for the MOX FFP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality, water quality, and land use from construction of the equipment disassembly and packaging facility will be an indistinguishable fraction of those resulting from construction of the reference MOX FFP.

Ecological Effects. Land requirements for the equipment disassembly and packaging facility at the MOX FFP are small and are included in the overall area occupied by the MOX FFP. Ecological impacts of construction which may be caused by excavation, noise, dust, and human activity will be indistinguishable from the overall impacts of the MOX FFP.

About 800 m^3 of water will be used during the 1-year construction period or about 2.2 m^3/day. This water will be supplied by the R River near the reference site; its removal will have no measurable effect on the mean annual river flow (about 1.1×10^7 m^3/day) or on the ecology of the river.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the equipment disassembly and packaging facility are given in Table 6.2.2-2.

TABLE 6.2.2-2. Utilities and Materials Required for Planned Operation of the Equipment Disassembly and Packaging Facility of the MOX FFP

Resource	Average Annual Use
Water, m^3	40
Acetylene, kg	50
Electricity, kWh	300,000
Manpower, man-yr	2.7

Personnel will be assigned to perform equipment disassembly and packaging functions as necessary.

Process Effluents. The amounts of radionuclides that will contribute at least 1% to the total dose to a given organ from any pathway to man or that are otherwise of interest are shown in Table 6.2.2-3.

No nonradioactive pollutants will be released to the biosphere from planned operation of the equipment disassembly and packaging facility. About 1.2×10^6 MJ/yr of heat (electrical load expressed as waste heat) will be released along with heating and ventilation air. There are no identifiable liquid effluent streams.

Physical, Chemical, and Thermal Effects. All liquid and solid waste disposal for the equipment disassembly and packaging facility is part of the overall MOX FFP operation. No distinguishable effects on air quality, water quality, or land use will result from disposal operations. The use of about 40 m^3 of process water required by the facility annually will have no perceptible impact on local water supplies.

TABLE 6.2.2-3. Radionuclides Released to the Biosphere by the Equipment Disassembly and Packaging Facility at the MOX FFP

Radionuclide	Quantity, Ci/yr
^{237}U	1.2×10^{-10}
^{238}Pu	1.5×10^{-7}
^{239}Pu	1.0×10^{-8}
^{240}Pu	2.1×10^{-8}
^{241}Am	7.5×10^{-8}
^{242}Cm	4.6×10^{-6}

Radiological Effects. Doses to individuals in the vicinity of the facility were calculated based on the releases of radionuclides listed in Table 6.2.2-3; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation, the only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.2.2-4. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

Table 6.2.2-4. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the Equipment Disassembly and Packaging Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
Air submersion	3.8×10^{-17}	3.8×10^{-17}	3.8×10^{-17}	3.8×10^{-17}	3.8×10^{-17}
Inhalation	7.5×10^{-10}			4.4×10^{-9}	1.7×10^{-9}
Ingestion	2.3×10^{-14}				9.5×10^{-12}
Total	7.5×10^{-10}	3.8×10^{-17}	3.8×10^{-17}	4.4×10^{-9}	1.7×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 6.2.2-5 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately

2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with less than 0.001 man-rem received from process sources as given in Table 6.2.2-6.

TABLE 6.2.2-5. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Equipment Disassembly and Packaging Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.0×10^{-12}	1.0×10^{-12}	1.0×10^{-12}	1.0×10^{-12}
Inhalation	1.9×10^{-6}		1.1×10^{-4}	4.4×10^{-5}
Ingestion	2.5×10^{-10}			1.1×10^{-8}
Total	1.9×10^{-6}	1.0×10^{-12}	1.1×10^{-4}	4.4×10^{-5}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 10 man-rem. Table 6.2.2-6 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 6.2.2-6. Summary of Annual Total-Body Doses Received from Operation of the Equipment Disassembly and Packaging Facility and from Naturally Occurring Sources

	Dose, man-rem
Equipment disassembly and packaging facility	
Process work force (30 yr)	10
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.2.2-7 and 6.2.2-8 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.2.2-9. For perspective, the populaton dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, compared with 0.0012 man-rem received from the equipment disassembly and packaging facility.

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

TABLE 6.2.2-7. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released by the Equipment Disassembly and Packaging Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	1.2×10^{-15}	1.2×10^{-15}	1.2×10^{-15}	1.2×10^{-15}
Inhalation	4.7×10^{-18}		2.5×10^{-7}	1.0×10^{-6}
Ingestion	3.6×10^{-11}			1.5×10^{-10}
Total	3.6×10^{-11}	1.2×10^{-15}	2.5×10^{-7}	1.0×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.
a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.2.2-8. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the Equipment Disassembly and Packaging Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.0×10^{-11}	3.0×10^{-11}	3.0×10^{-11}	3.0×10^{-11}
Inhalation	1.2×10^{-3}		6.5×10^{-3}	2.6×10^{-2}
Ingestion	3.9×10^{-7}			1.6×10^{-5}
Total	1.2×10^{-3}	3.0×10^{-11}	6.5×10^{-3}	2.6×10^{-2}

TABLE 6.2.2-9. Summary of 70-Year Total-Body Doses Received from Operation of the Equipment Disassembly and Packaging Facility and from Naturally Occurring Sources

	Dose, man-rem
Equipment disassembly and packaging facility	
Process work force (30 yr)	300
Population (within 80 km)	0.024
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. The only non radiological pollutant that will be released directly to the environment is 1.2×10^6 MJ/yr of heat, which represents about 10% of the heat released via the MOX FPP stack. No ecological consequences are expected.

Approximately 40 m^3/yr of water will be needed for decontamination solution. This water will be withdrawn from the R River near the reference site and represents an insignificant fraction of the average annual river flow of 3.9×10^9 m^3. Decontamination solutions will be collected in a sump and will be filtered before reuse or treatment as liquid waste. There are no planned releases of liquid effluents to the environment.

No adverse ecological impacts are expected from routine operation of the equipment disassembly and packaging facility at the MOX FFP.

Environmental Effects Related to Postulated Accidents. One minor accident has been postulated for the equipment disassembly and packaging facility at the MOX FFP. The accident scenario is described in DOE/ET-0028[1] and the accident is listed below.

Accident Number	Description
4.3.2	Failed equipment drop from crane

There are no releases of radioactive or nonradioactive material during this accident; therefore, no significant effects are anticipated.

No moderate or severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

REFERENCES FOR SECTION 6.2.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

6.2.3 Compactable Combustible Waste (DOE/ET-0028 Sec. 4.4)

Three methods have been used for treating general trash and combustible waste. Two of these, incineration and packaging without treatment, are described in this section. Incineration consists of burning the waste, thereby decreasing the waste volume and rendering it noncombustible and treating the off-gas for removal of radionuclides and other noxious materials. Packaging without treatment consists of packaging general trash and ventilation filters in steel drums for interim storage or burial at the repository. The third alternative, compaction, consists of compacting the waste and packaging it in steel drums for interim storage or burial at the repository. All three methods have been widely used in industry.

6.2.3.1 Incineration (DOE/ET-0028 Sec. 4.46)

The incineration process treats combustible general trash and spent ventilation filters generated at a mixed-oxide fuel fabrication plant (MOX FFP). The reference MOX FFP incineration process is described in the simplified flow diagram in Figure 6.2.3-1.

At the MOX FFP, ventilation filters have aluminum frames with glass fiber filter media. The filter medium is pressed from the frames, pelletized, and packaged in 55-gal drums along with the crushed frames for final disposal. In the incineration process the general trash is incinerated to reduce its volume and render it noncombustible. Because of the small volume of material involved, the process does not provide for concentrating the off-gas scrubbing solution or blowdown solution.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

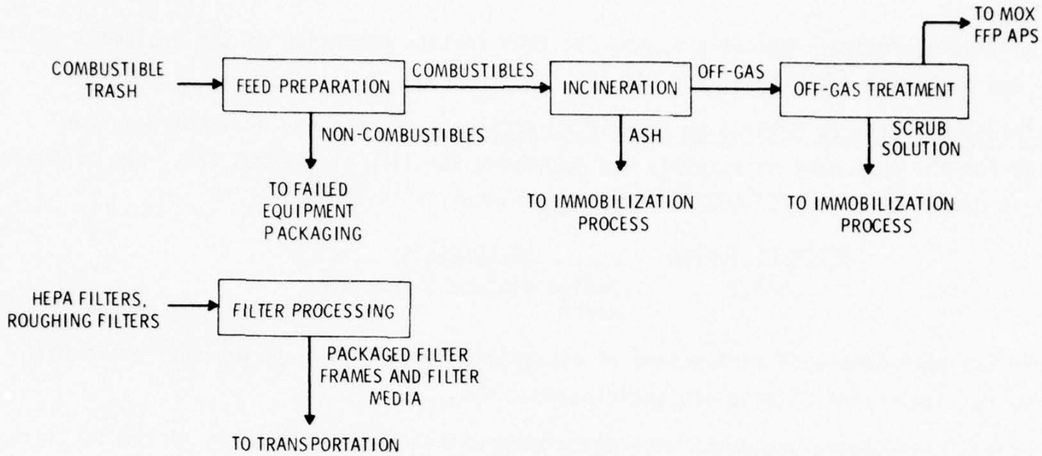


FIGURE 6.2.3-1. Treatment of Combustible Wastes and Filters at the MOX FFP Waste Incineration Facility

Resource Commitments. The waste incineration facility for general trash and combustible waste will occupy an area of 510 m^2, which includes the off-gas blower room, off-gas treatment, waste receiving and feed preparation area, incineration feed glove box train, storage area for untreated waste, and the high-efficiency particulate air (HEPA) filter compactor. The incineration facilities will be constructed as part of the MOX FFP. Land commitment will be indistinguishable from that committed for the MOX FFP.

Water used during construction is estimated to be 1.1×10^3 m^3. Withdrawal of this amount of water from the R River is judged to be insignificant with respect to other downstream uses. During the construction period wells could probably supply the required amount of water without environmental consequence.

Materials committed for construction of the waste incineration facility are:

Steel, MT	90
Copper, MT	0.9
Lumber, m^3	25
Concrete, m^3	500

Energy resources committed for construction are:

Propane, m^3	11
Diesel fuel, m^3	110
Gasoline, m^3	76
Electricity	
Peak demand, kW	120
Total consumption, kW	60,000

Manpower requirements for construction of the waste incineration facility will amount to 49 man-yr, which will be integrated with labor schedules for the MOX FFP.

No additional transportation requirements have been identified beyond those for the MOX FFP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality, water quality, and land use from construction of the waste incineration facility will be indistinguishable from those resulting from construction of the reference MOX FFP (Section 6.5).

Ecological Effects. Ecological impacts of construction that may be caused by excavation, noise, dust, and human activity will be indistinguishable from the overall impacts of the MOX FFP.

About 1000 m^3 of water will be used during the assumed 1-year construction period. This water will be supplied from the R River near the reference site; its removal will have no measurable effect on river flow (about 1.1×10^7 m^3/day) or on the ecology of the river.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the waste incineration facility are given in Table 6.2.3-1.

TABLE 6.2.3-1. Utilities and Materials Required for Planned Operation of the Waste Incineration Facility at the MOX FFP

Resource	Average Annual Use
Electricity, kWh	1.0×10^6
Propane, m^3	7.0×10^3
Water, m^3	
Cooling tower makeup	7.8×10^2
Process water	1.3×10^3
NaOH, MT	3.8×10^3
Cardboard boxes	
(30 x 30 x 61 cm)	4.6×10^2
Barrels (55-gal drums)	5.0×10^1
Manpower, man-yr	4

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the MOX FFP are shown in Table 6.2.3-2. The radionuclides listed are those that will contribute at least 1% of the total dose to a given organ from any pathway to man.

TABLE 6.2.3-2. Radionuclides Released to the Biosphere from the Waste Incineration Facility at the MOX FFP (Ci/yr)

Radionuclide	Release
^{237}U	2.4×10^{-17}
^{238}Pu	3.0×10^{-14}
^{239}Pu	2.1×10^{-15}
^{240}Pu	4.2×10^{-15}
^{241}Pu	9.3×10^{-13}
^{241}Am	1.5×10^{-15}

Nonradioactive materials released via the atmospheric protection system at the MOX FFP are presented in Table 6.2.3-3.

TABLE 6.2.3-3. Nonradioactive Materials Released via the 20-m Stack of the Atmospheric Protection System at the MOX FFP

Pollutant	Amount, MT/yr
Hydrogen chloride	0.008
Sulfur oxide	0.015
Nitrogen oxide	0.033
Carbon monoxide	0.017

The waste incineration facility, which operates about 560 hr/yr, produces about 1.8×10^6 MJ/yr of heat that will be rejected to the atmosphere. Of this quantity about 2.3×10^5 MJ/yr will be released via the plant stack and about 1.6×10^6 MJ/yr via the cooling tower. The total heat release represents about one-fourth of the total heat rejected by the MOX FFP.

From cooling water circulated to the cooling tower, a blowdown of 0.02 m^3/hr can be expected. About 1.3×10^2 m^3/yr of process water will be circulated back to the MOX FFP. There are no planned releases of radioactive materials to ground or water.

Physical, Chemical, and Thermal Effects. Atmospheric effects resulting from operation of the waste incineration facility may include air quality impacts resulting from emission of non-radioactive pollutants and release of waste heat. The atmospheric effect of waste heat rejection will be limited to a small occurrence of fogging at the outfall of discharge or from the cooling tower.

Annual average and maximum ambient ground level concentrations of pollutants released from the incineration process at the MOX FFP were computed using annual average dispersion factors ($\overline{\chi}/Q'$) values developed from annual average joint frequency distribution data listed in the reference environment. These concentrations are listed in Table 6.2.3-4 along with applicable Federal air quality standards.

TABLE 6.2.3-4. Ground Level Concentrations of Pollutants Measured at the Fenceline (1100 m) and Compared with Federal Air Quality Reference Values

Pollutant	Concentration, $\mu g/m^3$ Maximum	Concentration, $\mu g/m^3$ Average	Air Quality $\mu g/m^3$ Reference Values
Hydrogen chloride	2.0×10^{-4}	1.0×10^{-4}	5×10^{3} (a)
Sulfur oxide	4.0×10^{-4}	2.0×10^{-4}	8×10^{1} (b)
Nitrogen oxide	8.0×10^{-4}	4.0×10^{-4}	1×10^{2} (b)
Carbon monoxide	4.0×10^{-4}	2.0×10^{-4}	4×10^{4} (b)

a. Source: Threshold Limit Values for Current Year (1976), American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.
b. Federal Air Quality Standards.

There are no planned direct releases of nonradioactive liquid or solid wastes to land or to surface or groundwaters from the incineration process. All liquid and solid waste disposal for the process is part of the overall MOX FFP operation. Therefore, no effects are expected.

Radiological Effects. Doses to individuals in the environs of the MOX FFP waste incineration facility were calculated based on the releases of radionuclides listed in Table 6.2.3-2; pathways, demography, and other parameters as described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the facility, the only pathway for radionuclides to man is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.2.3-5. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 6.2.3-5. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the Waste Incineration Facility at the MOX FFP (rem)

Pathway	Total Body	Thyroid (child)(a)	Thyroid(b)	Lung	Bone
Air submersion	5.2×10^{-22}	5.2×10^{-22}	5.2×10^{-22}	5.2×10^{-22}	5.2×10^{-22}
Inhalation	1.0×10^{-15}			6.0×10^{-14}	2.3×10^{-14}
Ingestion	3.0×10^{-19}				1.3×10^{-17}
Total	1.0×10^{-15}	5.2×10^{-22}	5.2×10^{-22}	6.0×10^{-14}	2.3×10^{-14}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor (χ/Q') of 3.6×10^{-7} sec/m^3.
a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in Appendix A. Table 6.2.3-6 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with less than 0.001 man-rem received from radioactive material released by the incineration facility.

TABLE 6.2.3-6. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Waste Incineration Facility at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.3×10^{-17}	1.3×10^{-17}	1.3×10^{-17}	1.3×10^{-17}
Inhalation	2.6×10^{-12}		1.5×10^{-9}	6.0×10^{-10}
Ingestion	3.2×10^{-15}			1.5×10^{-13}
Total	2.6×10^{-12}	1.3×10^{-17}	1.5×10^{-9}	6.0×10^{-10}

The annual total-body dose to the work force associated with the waste incineration facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 30 man-rem. Table 6.2.3-7 summarizes the annual total-body dose to the work force and the general public from process and naturally occurring sources in the year 2000.

TABLE 6.2.3-7. Summary of Annual Total-Body Doses Received During Normal Operation of the MOX FFP Waste Incineration Facility and Naturally Occurring Sources

	Man-rem
Waste incineration facility	
Process work force (30 yr)	30
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.2.3-8 and 6.2.3-9 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.2.3-10. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with less than 0.001 man-rem received from the incineration facility.

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (See Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report 100 to 800 health effects are postulated to result in the exposed population per million man-rem.

TABLE 6.2.3-8. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released by the Waste Incineration Facility at the MOX FFP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	1.5×10^{-20}	1.5×10^{-20}	1.5×10^{-20}	1.5×10^{-20}
Inhalation	6.4×10^{-13}		3.4×10^{-12}	1.4×10^{-11}
Ingestion	4.8×10^{-16}			1.9×10^{-14}
Total	6.4×10^{-13}	1.5×10^{-20}	3.4×10^{-12}	1.4×10^{-11}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.2.3-9. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the Waste Incineration Facility at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	4.0×10^{-16}	4.0×10^{-16}	4.0×10^{-16}	4.0×10^{-16}
Inhalation	1.7×10^{-8}		8.7×10^{-8}	3.6×10^{-7}
Ingestion	5.3×10^{-12}			2.1×10^{-10}
Total	1.7×10^{-8}	4.0×10^{-16}	8.7×10^{-8}	3.6×10^{-7}

TABLE 6.2.3-10. Summary of 70-Year Total-Body Doses Received During Normal Operation of the MOX FFP Waste Incineration Facility and from Naturally Occurring Sources

	Dose, man-rem
Waste incineration facility	
Process work force (30 yr)	900
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. Dilution and dispersal of nonradioactive materials after their release will result in maximum ground level concentrations that are several orders of magnitude less than Federal air quality standards. No detrimental ecological effects are expected from these small releases.

Approximately 1.8×10^6 MJ/yr of heat will be released to the atmosphere during facility operation. This release of heat, principally via evaporation of water from the cooling tower, will not adversely affect nearby plant and animal communities.

Water requirements for the incineration facility will be 1.3 x 10^3 m^3/yr for process and 7.8 x 10^2 m^3/yr for cooling tower makeup. Facility cooling water will be circulated through the MOX FFP mechanical cooling tower and will comprise about one-fourth of the total volume of 62 ℓ/sec of water circulating through the cooling tower system. The total contribution of the incineration facility to the cooling tower drift, evaporation, and blowdown will be less than 1.4 ℓ/sec. Facility blowdown at the rate of 0.22 ℓ/sec during the 560 hr of operation per year will be discharged to a sanitary treatment system where it will be diluted with sanitary waste water and discharged to the R River. The temperature increase in the blowdown is assumed to be about 17°C. This small discharge of heat will have no discernible effect on the aquatic ecosystem.

Environmental Effects Related to Postulated Accidents. Two minor accidents were postulated for the waste incineration facility. It was concluded that neither accident would release any radioactive material to the biosphere. The accident scenarios are described in DOE/ET-0028[1] and are listed below.

Accident Number	Description
4.4.1	Loss of cooling water to incinerator off-gas treatment system
4.4.2	Minor fire in feed preparation line

Three accidents were postulated to release radioactive materials. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.4.3	Major fire in feed preparation line
4.4.4	Explosion in feed preparation line
4.4.5	Incinerator explosion

Of these accidents, incinerator explosion (Accident 4.4.4) was judged to be most severe and was taken as representative of the set.

For this accident it was assumed that an explosion in the process line released about 2% of the annual inventory of radioactive material to the cell atmosphere for a period of 30 min. The radionuclides entering the atmosphere via the MOX FFP stack are listed in Table 6.2.3-11.

TABLE 6.2.3-11. Radionuclides Released to the Atmosphere from a Moderate Accident at the MOX FFP Waste Incineration Facility

Radionuclide	Release, Ci
^{237}U	2.3 x 10^{-10}
^{238}Pu	2.9 x 10^{-7}
^{239}Pu	2.0 x 10^{-8}
^{240}Pu	4.0 x 10^{-8}
^{241}Pu	8.8 x 10^{-6}
^{241}Am	1.5 x 10^{-8}

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 6.2.3-12. The largest dose calculated was 2.3×10^{-5} rem to the lung, which is about 1% of the nominal variation in dose received from naturally occurring sources at a given location.

TABLE 6.2.3-12. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident at the MOX FFP Waste Incineration Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	1.3×10^{-13}	7.2×10^{-14}	7.2×10^{-14}	7.2×10^{-14}	7.2×10^{-14}
Inhalation		4.4×10^{-6}		2.3×10^{-5}	9.5×10^{-5}
Total	1.3×10^{-13}	4.4×10^{-6}	7.2×10^{-14}	2.3×10^{-5}	9.5×10^{-5}

No severe accidents were postulated within the design basis of the facility and non-design basis accidents were not considered.

No accidents or unusual events have been identified that would result in the release of pollutants that would produce a significant effect on the environment.

6.2.3.2 Packaging Without Treatment (DOE/ET-0028 Sec. 4.4.7)

Packaging MOX FFP combustible and compactable trash without treatment is an alternative to incineration or compaction of wastes prior to packaging.

The reference process and facility is virtually identical to packaging of low-level waste without treatment at a fuel reprocessing plant (FRP) (Section 5.2.6) except that the capacity of the reference facility is smaller, and its HEPA filters are packaged in 80-gal rather than 55-gal drums. The facility has a capacity of 310 m^3/yr and includes storage capacity for 3 months' drummed wastes.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and reference facility construction may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The packaging facility will occupy an area of 220 m^2 which includes storage for new and filled drums and a truck loading bay. The packaging facility will be constructed as a part of the MOX FFP. Land commitment will be indistinguishable from that committed to the MOX FFP.

Water used during construction is estimated to be 800 m^3. Withdrawal of this amount of water is judged to be insignificant with respect to other downstream uses. During the construction period, wells could supply the required amount of water without consequence.

Materials committed for construction of the packaging facility are:

Steel	90 MT
Copper	2.7 MT
Zinc	0.9 MT

Aluminum	0.9 MT
Lumber	25 m^3
Concrete	450 m^3

Energy resources committed for facility construction are:

Propane	7.5 m^3
Diesel fuel	75 m^3
Gasoline	45 m^3
Electricity	
Peak demand	70 kW
Total consumption	45,000 kWh

Manpower requirements for construction of the packaging facility will amount to 2.9×10^1 man-yr, which will be integrated with labor schedules for the MOX FFP.

No additional transportation requirements have been identified beyond those for the MOX FFP. No site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the packaging facility will be an indistinguishable fraction of those resulting from construction of the MOX FFP (Section 6.5).

Ecological Effects. The packaging facility will be part of the MOX FFP and will occupy less than 1% of the MOX FFP exclusion area. The ecological impacts that may result from facility construction will be indistinguishable from those of the overall MOX FFP complex. These impacts may include elimination and alteration of vegetation cover; destruction of animal habitat; and disturbance of animals caused by noise, dust, and human activity.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the packaging facility are given in Table 6.2.3-13.

TABLE 6.2.3-13. Utilities and Materials Required for Planned Operation of the Packaging Without Treatment Facility at the MOX FFP

Resource	Average Annual Use
Electricity, kWh	50,000
Wooden pallets	470
Barrels	
55-gal drums	1,050
80-gal drums	350
Manpower, man-yr	1.6

Process Effluents. There are no planned releases to the biosphere of nonradioactive effluents resulting from operation of the packaging facility. Planned releases of radioactive materials will be less than 5% of the total release via incineration as given in Section 6.2.3.1. The magnitude of these releases is low enough to not warrant additional comment, but the releases are included in Section 6.2.3.3 for comparison purposes.

Physical, Chemical, and Thermal Effects. There are no planned direct releases of nonradioactive pollutants from operation of the MOX FFP packaging facility; therefore, no physical, chemical, or thermal effects will occur. Liquid and solid waste disposal for the process is part of the overall MOX FFP operation. Heat release to the atmosphere amounts to about 1.5×10^5 MJ/yr.

Radiological Effects. Radioactive material in quantities amounting to about 1×10^{-4} of those from the incineration process will be released during planned operation of the packaging facility. These releases are so small that no radiological effects will result.

Ecological Effects. There will be no significant releases of wastes during normal operation of the packaging facility. Small amounts of water used for decontamination of waste drums will be collected in a sump and pumped to another facility where it will be processed as liquid waste. No ecological impacts from operation of the packaging facility are expected.

Environmental Effects Related to Postulated Accidents. Two minor accidents were postulated for packaging general trash and combustible waste without treatment at the MOX FFP. The accident scenarios are described in DOE/ET-0028[1] and the accidents are listed below:

Accident Number	Description
4.4.6	Ruptured waste bag spill to floor
4.4.7	Fire in one barrel of bagged trash

Accident 4.4.6 was postulated to release no radioactive material. Accident 4.4.7 was considered to be no worse than a fire in the bitumen immobilization facility at the FRP and the consequences of that Accident 4.7.6 (Section 5.2.6.3) were assigned to Accident 4.4.7. The estimated quantities of radionuclides released to the atmosphere are presented in Table 6.2.3-14.

Annual doses to the maximum individual and the regional population were calculated for the releases given in Table 6.2.3-14. Seventy-year dose commitments for each group were also calculated using average annual dispersion factors. In no case was the resulting dose greater than 1×10^{-11} rem for any individual dose and most often was several orders of magnitude less and does not constitute a radiological impact.

One accident is postulated to release radioactive material in amounts larger than those released by minor accidents. It is classified as a moderate accident and is listed below.

Accident Number	Description
4.4.8	Spent HEPA filter spilled to floor

TABLE 6.2.3-14. Radionuclides Released to the Atmosphere from a Minor Accident at the Packaging Without Treatment Facility at the MOX FFP

Radionuclide	Release, Ci
^{3}H	5.0×10^{-5}
^{14}C	1.3×10^{-12}
^{60}Co	4.9×10^{-12}
^{90}Sr	7.3×10^{-12}
^{95}Zr	4.1×10^{-11}
^{95}Nb	9.1×10^{-11}
^{106}Ru	2.3×10^{-9}
^{134}Cs	1.4×10^{-11}
^{137}Cs	1.1×10^{-11}
^{238}Pu	6.6×10^{-11}
^{239}Pu	4.3×10^{-12}
^{240}Pu	8.8×10^{-12}
^{241}Pu	2.2×10^{-9}

Accident 4.4.7 was considered to be no worse than a process off-gas cleanup system failure in a waste solidification facility, and the consequences of Accident 4.1.8 (discussed in Sections 5.2.2 and 5.2.6.3) were assigned to Accident 4.4.7.

The estimated quantities of radionuclides released to the atmosphere are presented in Table 6.2.3-15. The 70-year dose commitment to the maximum individual from this accident is presented in Table 6.2.3-16. The largest dose calculated is on the order of the annual variation in dose received from naturally occurring sources at a given location and is expected to be without significance.

No severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered. No accidents or unusual events have been identified that would result in the release of ecologically significant amounts of nonradioactive materials.

6.2.3.3 Comparison of Environmental Effects Between General Trash and Combustible Waste Treatments at the MOX FFP

Selected aspects of construction and operation of the general trash and combustible waste treatment alternatives (incineration and packaging without treatment) are presented in Tables 6.2.3-17 through 6.2.3-19.

TABLE 6.2.3-15. Radionuclides Released to the Atmosphere from a Moderate Accident in the Packaging Without Treatment Facility at the MOX FFP

Radionuclide	Release, Ci
^{90}Sr	1.2×10^{-3}
^{95}Nb	1.4×10^{-4}
^{106}Ru	3.6×10^{-3}
^{125m}Te	4.5×10^{-5}
^{127m}Te	8.1×10^{-6}
^{134}Cs	2.3×10^{-3}
^{137}Cs	1.8×10^{-3}
^{144}Ce	4.5×10^{-3}
^{154}Eu	1.2×10^{-4}
^{239}Pu	3.4×10^{-8}
^{241}Am	1.3×10^{-5}
^{242}Cm	1.9×10^{-4}
^{244}Cm	1.3×10^{-4}

Note: Non-transuranic radionuclides are listed because the umbrella accident for moderate accidents was developed for the FRP. No non-transuranic radionuclides would be expected in the MOX FFP.

TABLE 6.2.3-16. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident in the Packaging Without Treatment Facility at the MOX FFP

Organ	Dose, rem
Total body	2×10^{-4}
Thyroid	7×10^{-7}
Lung	3×10^{-3}
Bone	2×10^{-3}
Skin	2×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 3.6×10^{-7} sec/m^3.

TABLE 6.2.3-17. Comparison of Resource Commitments for Construction of Alternative General Trash and Combustible Waste Treatment Facilities at the MOX FFP

Resource	Incineration	Packaging Without Treatment
Land, m^2	5.2×10^2	2.2×10^2
Water, m^3	1.1×10^3	8.0×10^2
Materials		
Steel, MT	9.0×10^1	9.0×10^1
Copper, MT	9.0×10^{-1}	2.7
Lumber, m^3	2.5×10^1	2.5×10^1
Concrete, m^3	5.0×10^2	4.5×10^2
Zinc, MT		9.0×10^{-1}
Aluminum, MT		9.0×10^{-1}
Energy		
Propane, m^3	7.0×10^3	7.5
Diesel fuel, m^3	1.1×10^2	7.5×10^1
Gasoline, m^3	7.6×10^1	4.5×10^1
Electricity, kWh	6.0×10^4	4.5×10^4
Manpower, man-yr	4.9×10^1	2.9×10^1

TABLE 6.2.3-18. Comparison of Nonradiological Aspects of Operating Alternative General Trash and Combustible Waste Treatment Facilities at the MOX FFP

	Annual Quantity	
	Incineration	Packaging Without Treatment
Water consumed, m^3	7.8×10^2	
Materials		
Wooden pellets		4.7×10^2
Boxes (0.06 m^3 cardboard)	4.6×10^2	
Drums, steel		
55-gal	5.0×10^1	1.1×10^3
80-gal		3.5×10^2
Sodium hydroxide, MT	3.8×10^3	
Energy		
Electricity, kWh	1.0×10^6	5.0×10^4
Propane, m^3	7.0×10^3	
Manpower, man-yr	4.0	1.6
Nonradioactive effluents, MT		
Hydrogen chloride	8.5×10^{-3}	
Sulfur oxide	1.5×10^{-2}	
Nitrogen oxide	3.3×10^{-2}	
Carbon monoxide	1.7×10^{-2}	
Waste heat, MJ		
Via cooling tower	1.6×10^6	
Via plant stack	2.4×10^5	1.5×10^5

TABLE 6.2.3-19. Comparison of Radiological Aspects of Operating Alternative General Trash and Combustible Waste Treatment Facilities at the MOX FFP

	Incineration	Packaging Without Treatment
Principal Radionuclides Released to the Atmosphere, Ci/yr		
^{237}U	1.6×10^{-15}	6.6×10^{-17}
^{238}Pu	2.0×10^{-12}	8.4×10^{-14}
^{239}Pu	1.4×10^{-13}	5.7×10^{-15}
^{240}Pu	2.7×10^{-13}	1.1×10^{-14}
^{241}Pu	6.0×10^{-11}	2.6×10^{-12}
^{241}Am	1.0×10^{-13}	4.2×10^{-15}
Dose to Maximum Individual from 70-Year Residency (30-year plant life), rem		
Total body	6.4×10^{-13}	2.6×10^{-14}
Thyroid	1.5×10^{-20}	6.6×10^{-22}
Lung	3.4×10^{-12}	1.4×10^{-13}
Bone	1.4×10^{-11}	5.5×10^{-13}
(Dose from naturally occurring sources for same period, 7 rem)		
Dose to Regional Population from 70-Year Residency (2 million persons, 30-year plant life), man-rem		
Total body	1.7×10^{-8}	6.6×10^{-10}
Thyroid	4.0×10^{-16}	1.7×10^{-17}
Lung	8.7×10^{-8}	3.6×10^{-9}
Bone	3.6×10^{-7}	1.5×10^{-8}
(Dose from naturally occurring sources for same period, 1.4×10^{7} man-rem)		
Dose to Process Work Force (30-year plant life), man-rem		
Total body	9.0×10^{2}	1.8×10^{2}
70-Year Dose Commitment to Maximum Individual from Most Serious Accident Identified, rem		
Total body	4.4×10^{-6}	2×10^{-4}

Notes: No radioactive material is released from either process to water or ground.

Commitments of energy and materials for construction of either facility are comparable. Resource commitments are either too small or not sufficiently different between the alternatives to form a basis for selection.

In terms of process operation, the packaging without treatment process requires only a nominal amount of electricity and manpower. Incineration requires cooling water, about ten times more electricity, and a number of other materials not required for the packaging without treatment process. The incineration process approximately doubles the pollutant load released to the atmosphere from the MOX FFP.

Minimum treatment of combustible waste results in the need for 1050 55-gal (0.2 m^3) drums per year and 350 80-gal (0.3 m^3) drums per year. The incineration process requires 200 55-gal drums per year for containment of incinerator ash and scrubber blowdown if such wastes are immobilized by cement or 100 55-gal drums per year if immobilized by bitumen. (Immobilization of wastes is discussed in Section 5.2.7.) Thus the total of 1050 55-gal and 350 80-gal drums per year compares with a total of about 200 55-gal drums if cement immobilization is used and about 100 drums if bitumen immobilization is used. In terms of 55-gal drums, minimum treatment of incinerator wastes requires the use of five times more drums than those needed for cement immobilization and ten times more drums than those needed for bitumen immobilization. The number of drums may not be important in terms of resource commitments, but the number also reflects transportation requirements and final isolation volume requirements.

In packaging without treatment of combustible wastes, 1400 drums have surface activities of <0.2 R/hr and 36 drums can be shipped by truck at one time. Thus, about 40 trips from the MOX FFP to a repository will be required annually. The reference distance from the MOX FFP to a repository is 2.4×10^3 km so that the annual shipping distance would be about 9.6×10^4 km one way. Since the containers must be returned, the total distance chargeable to packaging without treatment of combustible waste would be about 1.9×10^5 km.

If the incineration process is chosen and is followed by cement immobilization, 200 drums will have surface activities of <0.2 R/hr and if shipped 36 at a time will result in six trips per year, with a total round-trip distance of 2.8×10^4 km/yr. If the incineration process is followed by bitumen immobilization of ash and scrubber blowdown, 100 drums will have surface activities of <0.2 R/hr and if shipped 36 drums per trip will result in three trips, with a total round-trip distance of 1.4×10^4 km/yr. This analysis indicates that, in terms of transportation costs (i.e., fuel, exhaust emissions, and nonradiological traffic injuries and fatalities), incineration with cement immobilization is about one-fifth that of the minimum treatment option and bitumen immobilization is about one-tenth that of the minimum treatment option.

Trucks used to ship non-high-level transuranic wastes plus their cargo are expected to weigh about 23 MT. At a rate of 2.2×10^4 MT-km/m^3 of diesel fuel, the fuel requirements will amount to 1.0×10^{-3} m^3/km. Thus, minimum treatment requires about 190 m^3 of diesel fuel annually. The incineration option with cement immobilization of ash and scrubber blowdown requires about 28 m^3 of diesel fuel annually. Similarly, incineration with bitumen immobilization requires about 14 m^3 of diesel fuel annually.

In the above analysis, the assumption was made that transportation of non-high-level transuranic wastes would be by truck. Though not calculated, some reduction would be expected in fuel consumption, emissions, and traffic injuries and fatalities if wastes were shipped by rail.

For this same period, the dose to the population from direct radiation received from passing waste shipments can be calculated from the product of the dose received from direct radiation of 7.5 man-rem per million kilometers and the distance one way. For minimum treatment of combustible wastes and a distance of 1.9×10^5 km, a population dose of 1.4 man-rem/yr is obtained. At an assumed 10,000 man-rem per fatal cancer or serious genetic effect, direct radiation from shipment of untreated combustible waste does not result in one such case. The health effects from the incineration facility's contribution to direct dose from transportation would be even less significant. In radiological terms, routine operation of the packaging without treatment facility results in no release of radioactive materials to the atmosphere. The dose to the process work force for incineration is about five times that for the packaging without treatment process.

REFERENCES FOR SECTION 6.2.3

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

6.2.4 Concentrated Liquids, Wet Wastes, and Particulate Solids (DOE/ET-0028 Sec. 4.7)

The operation of any facility in the postfission nuclear fuel cycle results in the generation of radioactive concentrated liquids, wet wastes, and particulate solids. Prior to shipping and disposing of these wastes, their immobilization to a liquid-free form is necessary. This step may be done by a variety of methods, each with its own unique process characteristics. Immobilization of these wet wastes in bitumen and cement is discussed here as applied to a mixed-oxide fuel fabrication plant (MOX FFP).

6.2.4.1 Bitumen Immobilization at the MOX FFP (DOE/ET-0028 Sec. 4.7.4)

Immobilization of radioactive wet wastes in bitumen involves mixing the waste form with liquid bitumen or asphalt binder and placing it in 55-gal drums. The temperature of the binder (above 100°C) evaporates the free water, thus reducing the waste volume. The use of bitumen to immobilize radioactive wastes has been well demonstrated, largely through extensive operating experience in Europe. As discussed in ERDA 76-43,[1] several types of bitumen immobilization processes have been developed. This present study selects a continuous screw extruder process for the following reasons:

- The screw extruder bitumenization process operates at lower temperatures and with shorter residence times than the batch process, thus minimizing off-gas problems.
- The reference process uses well-demonstrated technology.
- The process is commercially available in the United States.

The reference bitumen immobilization facility is assumed to be an integral part of the MOX FFP and is constructed to withstand design basis earthquakes and tornados.

Figure 6.2.4-1 presents a process flow diagram of the bitumen immobilization process.

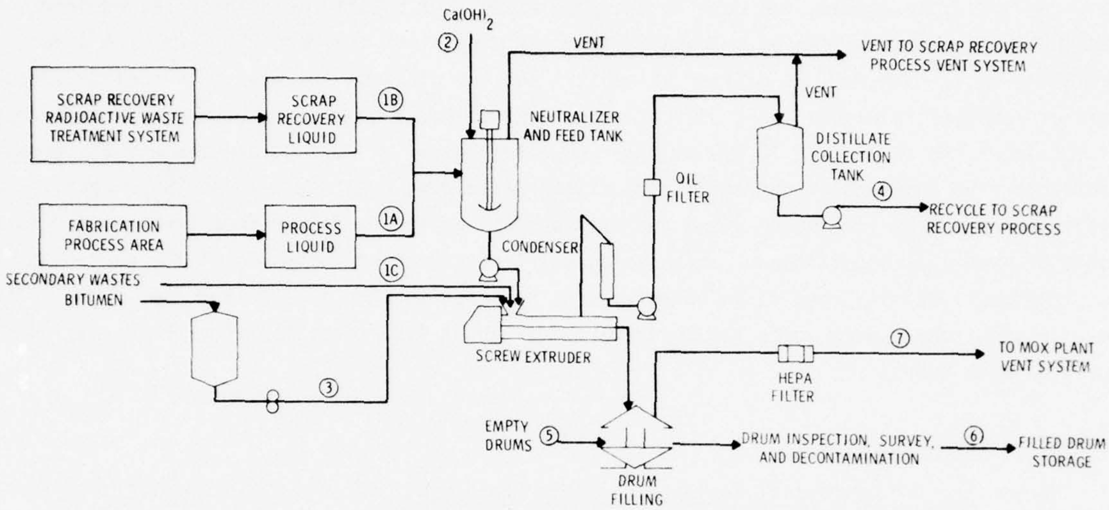


FIGURE 6.1.4-1. Process Flow Diagram for Bitumen Immobilization at a MOX FFP

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The bitumen immobilization facility will occupy about 450 m^2. This facility will be an integral part of the reference MOX FFP, whose structures will occupy about 60,000 m^2. Land use attributable to the facility is inconsequential by comparison and in any event would be preempted by construction of the MOX FFP.

Water used during construction is estimated to be 3 x 10^3 m^3. Withdrawal of this amount of water from the R River (described in the reference environment as having an average flow of 1.0 x 10^7 m^3/day) is judged to be insignificant with respect to other downstream uses. During the construction period wells could also supply the required amount of water without consequence.

Materials committed for construction of the bitumen immobilization facility are:

Steel	350 MT
Copper	5 MT
Lumber	100 m^3
Concrete	1500 m^3

Energy resources committed for construction are:

Propane	25 m^3
Diesel fuel	265 m^3
Gasoline	200 m^3
Electricity	
Peak demand	300 kW
Total consumption	200,000 kWh

Except for concrete and lumber, these quantities represent less than 10% of the amount required for construction of the reference MOX FFP. Concrete and lumber requirements are about 15% of those for the MOX FFP.

Manpower requirements for construction of the bitumen immobilization system amount to 120 man-yr, which will likely be integrated with labor schedules for the MOX FFP.

No additional transportation requirements for the bitumen immobilization facility have been identified beyond those for the MOX FFP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality, water quality, and land use from construction of the bitumen immobilization facility will be an indistinguishable fraction of those resulting from construction of the reference MOX FFP.

Ecological Effects. There will be no construction impacts for the bitumen immobilization facility apart from those of the MOX FFP. Land area requirements are on the order of 450 m^2 and are included with those of the MOX FFP.

Water used during the 4-year construction period of the entire MOX FFP is approximately 3×10^3 m^3 and will be withdrawn from the R River at the reference site. This amounts to less than the 0.01% of the river low flow and will not have an impact on the river biota. Since water used during construction of the bitumen immobilization facility is only a small percentage of that required for the entire MOX FFP, no additional ecological impacts are anticipated. A common system will probably be constructed to supply water to all facilities within the MOX FFP complex. Procedures to minimize disruption of current patterns and disturbance of the river bottom during construction of the intake for this system might be required.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the bitumen immobilization facility are given in Table 6.2.4-1.

TABLE 6.2.4-1. Utilities and Materials Required for Operating the Bitumen Immobilization Facility at the MOX FFP

Resource	Average Annual Use With Incineration
Electricity, kWh	2.2×10^5
Water consumed, m^3	8.2×10^2
Drums, 55-gal	5.3×10^2
Bitumen, MT	1.1×10^2
Lime, MT	5.9
Manpower, man-yr	2.3

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the bitumen immobilization facility and passing through the reference MOX FFP atmospheric protection system are shown in Table 6.2.4-2. The radionuclides listed are those that will contribute at least 1% of the total dose to a given organ from any pathway to man or that are otherwise of interest.

TABLE 6.2.4-2. Annual Release of Radionuclides to the Atmosphere from the Bitumen Immobilization Facility at the MOX FFP (Ci)

Radionuclide	With Incineration	Without Incineration
^{238}Pu	9.1×10^{-8}	
^{239}Pu	6.2×10^{-9}	8.1×10^{-12}
^{240}Pu	1.2×10^{-8}	
^{241}Pu	2.8×10^{-6}	3.6×10^{-9}
^{241}Am	2.3×10^{-8}	2.3×10^{-8}

The radionuclides entrained in air are derived from process off-gas. The total air flow through the process is estimated to be 0.06 m^3/sec or about 0.4% of the total flow of air through the MOX FFP. There are no planned releases of radioactive material to the biosphere via liquid effluent streams.

Odors released will be comparable to those of asphalt roofing or paving. Although the amounts and frequency have not been quantified, it is anticipated that measures will be taken to preclude the presence of offensive odors offsite.

The bitumen immobilization facility will release about 1.7×10^6 MJ of heat over 90 days of operation per year to the atmosphere. One-half of this amount will be direct release of sensible heat; one-half will go to the cooling water, which represents about 8% of the total MOX FFP cooling requirement. This water will be discharged to the R River at a ΔT of about 17°C. The amount of heat rejected to the cooling water will have an imperceptible effect on the MOX FFP thermal plume.

There is no direct ground disposal of nonradioactive liquid or solid wastes from the bitumen immobilization facility; therefore, no effects are predicted.

Radiological Effects. Doses to individuals in the vicinity of the reference MOX FFP bitumen immobilization facility were calculated based on the releases of radionuclides listed in Table 6.2.4-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the bitumen immobilization facility, the only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water. All doses were calculated for the process with incineration. (Doses without incineration would be less than those with incineration.)

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.2.4-3. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 6.2.4-3. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the MOX FFP Bitumen Immobilization Facility (rem)[a]

Pathway	Total Body	Thyroid (child)	Thyroid	Lung	Bone
Air submersion	5.7×10^{-17}	5.7×10^{-17}	5.7×10^{-17}	5.7×10^{-17}	5.7×10^{-17}
Inhalation	4.8×10^{-11}			3.1×10^{-9}	1.1×10^{-9}
Ingestion	1.7×10^{-14}				6.3×10^{-13}
Total	4.8×10^{-11}	5.7×10^{-17}	5.7×10^{-17}	3.1×10^{-9}	1.1×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.
a. After 30 years of release and accumulation in the environment.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 6.2.4-4 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 1.3×10^{-6} man-rem received from process sources, given in Table 6.2.4-4.

TABLE 6.2.4-4. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the MOX FFP Bitumen Immobilization Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.5×10^{-12}	1.5×10^{-12}	1.5×10^{-12}	1.5×10^{-12}
Inhalation	1.3×10^{-6}		8.0×10^{-5}	2.8×10^{-5}
Ingestion	1.9×10^{-10}			7.0×10^{-9}
Total	1.3×10^{-6}	1.5×10^{-12}	8.0×10^{-5}	2.8×10^{-5}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the bitumen immobilization facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 5 man-rem. Table 6.2.4-5 summarizes the annual total-body dose to the work force and the general public from process and naturally occurring sources in the year 2000.

TABLE 6.2.4-5. Summary of Annual Total-Body Doses Received from Operation of the MOX FFP Bitumen Immobilization Facility and from Naturally Occurring Sources

	Dose, man-rem
Bitumen immobilization facility	
Process work force (30 yr)	5
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.2.4-6 and 6.2.4-7 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.2.4-8. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem compared with <0.001 man-rem received from the bitumen immobilization facility.

TABLE 6.2.4-6. 70-year Doses to the Maximum Individual from Gaseous Effluents Released by the MOX FFP Bitumen Immobilization Facility (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.7×10^{-15}	1.7×10^{-15}	1.7×10^{-15}	1.7×10^{-15}
Inhalation	3.2×10^{-8}		1.7×10^{-7}	6.6×10^{-7}
Ingestion	2.8×10^{-11}			9.9×10^{-10}
Total	3.2×10^{-8}	1.7×10^{-15}	1.7×10^{-7}	6.6×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

TABLE 6.2.4-7. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the MOX FFP Bitumen Immobilization Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	4.4×10^{-11}	4.4×10^{-11}	4.4×10^{-11}	4.4×10^{-11}
Inhalation	8.2×10^{-4}		4.5×10^{-3}	1.7×10^{-2}
Ingestion	3.2×10^{-7}			1.1×10^{-5}
Total	8.2×10^{-4}	4.4×10^{-11}	4.5×10^{-3}	1.7×10^{-2}

TABLE 6.2.4-8. Summary of 70-Year Total-Body Doses Received from Operation of the MOX FFP Bitumen Immobilization Facility and from Naturally Occurring Sources

	Dose, man-rem
Bitumen immobilization facility	
Process work force (30 yr)	150
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. Cooling water at the rate of 820 m^3/yr will be required for the bitumen immobilization facility and will be supplied by the R River near the reference site. This volume is less than 0.01% of the minimum river flow and will have an insignificant effect on the river biota. The facility will contribute approximately 120 m^3/yr to the MOX FFP cooling tower blowdown, which will be discharged to the R River at a ΔT of 17°C. The chemical and thermal additions to the river from this small discharge will be quickly diluted by the much larger average river flow (1×10^7 m^3/day) and are not expected to have a perceptible effect on the river ecosystem.

Environmental Effects Related to Postulated Accidents. Several minor accidents associated with bitumen immobilization were identified which would be expected to lead to releases of radioactive material. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
4.7.1	Overfill waste drum
4.7.2	Drum filling control valve failure
4.7.3	Drum-filled level detector instrument failure
4.7.4	Container drop or rupture
4.7.5	Leakage in waste in transfer line
4.7.6	Bitumen fire

Based on the anticipated releases of all these minor accidents, weighted by their expected frequency of occurrence, an average annual release was postulated. The estimated quantities of radionuclides released to the biosphere are presented in Table 6.1.4-9.

TABLE 6.2.4-9. Annual Release of Radionuclides to the Atmosphere from Minor Accidents in the MOX FFP Bitumen Immobilization Facility

Radionuclide	Release, Ci
^{238}Pu	1×10^{-13}
^{239}Pu	6.2×10^{-14}
^{240}Pu	1.2×10^{-13}
^{241}Pu	2.8×10^{-11}
^{241}Am	2.3×10^{-13}

Annual doses were calculated for these releases for the maximum individual and the regional population. Seventy-year dose commitments for each group were also calculated. These doses were calculated using average annual atmospheric dispersion factors. In no case was the resulting dose greater than 2×10^{12} rem for any individual dose and most often was several orders of magnitude less and thus do not constitute a radiological impact. These doses are about five orders of magnitude lower than doses from routine operation.

There were also a number of accidents thought to involve larger releases of radioactive material. These are classed as moderate accidents[(2)] and are listed below.

Accident Number	Description
4.7.7	Cell HEPA failure with any minor accident
4.7.8	Cell HEPA failure with bitumen fire (in FRP transuranic process line)

Of these accidents, Accident 4.7.8 (cell HEPA failure with bitumen fire) was judged to be most severe and was taken as representative of the set. For this accident it was assumed that six open barrels catch fire during filling operations and that 1% of the activity in 1 kg of fixed wastes is released to the cell atmosphere from each barrel. A release period of 30 min is assumed. Expected frequency of this accident is 0.003 per year (recurrence once each 300 years). A moderate release of radioactive material could occur if a HEPA filter failed (from improper installation or smoke damage) concurrently. The radioactive release associated with such an event is presented in Table 6.2.4-10.

TABLE 6.2.4-10. Radionuclides Released to the Biosphere from Moderate Accidents in the MOX FFP Bitumen Immobilization Facility

Radionuclide	Release, Ci
^{239}Pu	4.2×10^{-13}
^{241}Am	1.2×10^{-9}

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 6.2.4-11. Numerically, the largest of these dose values is on the order of 2×10^{-7} rem/yr, which is considered to be insignificant in terms of negligible radiological effects. No accidents were postulated for the immobilization facility which would lead to more serious consequences. Non-design basis accidents were not considered.

TABLE 6.2.4-11. 70-Year Dose Commitment to the Maximum Individual Resulting from a Moderate Accident in the MOX FFP Bitumen Immobilization Facility

Organ	Dose, rem
Total body	9.7×10^{-9}
Bone	1.4×10^{-7}
Lung	7.5×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 3.6×10^{-7} sec/m^3.

6.2.4.2 Cement Immobilization at the MOX FFP (DOE/ET-0028 Sec. 4.7.5)

Immobilization of radioactive wet wastes in cement involves mixing the wastes with cement, placing the mixture into drums, and allowing the mixture to harden to a water-free product. Cement immobilization of radioactive wastes has been widely used in the United States. A variety of technologies have been developed, including in-drum mixers, drum tumblers, and in-line mixers, each of which is described in ERDA 76-43.(1) For this present study an in-drum mixing system has been selected based on the following reasons:

- Both liquid and dry wastes may be immobilized without altering the commercially available technology.
- The wastes are mixed inside the drums, thereby preventing external freezing of the waste-cement mixture.

The reference cement immobilization facility is assumed to be an integral part of the MOX FFP; it is constructed to withstand design basis earthquakes and tornados. As in the bitumen immobilization facility, the facility will handle all transuranic wastes generated at the MOX FFP. The process flow diagram of the reference facility is shown in Figure 6.2.4-2.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The cement immobilization facility will occupy an area of about 520 m^2. This facility will be constructed as a part of the MOX FFP, whose structures will occupy 60,000 m^2. Land commitment will be indistinguishable from that committed to the MOX FFP.

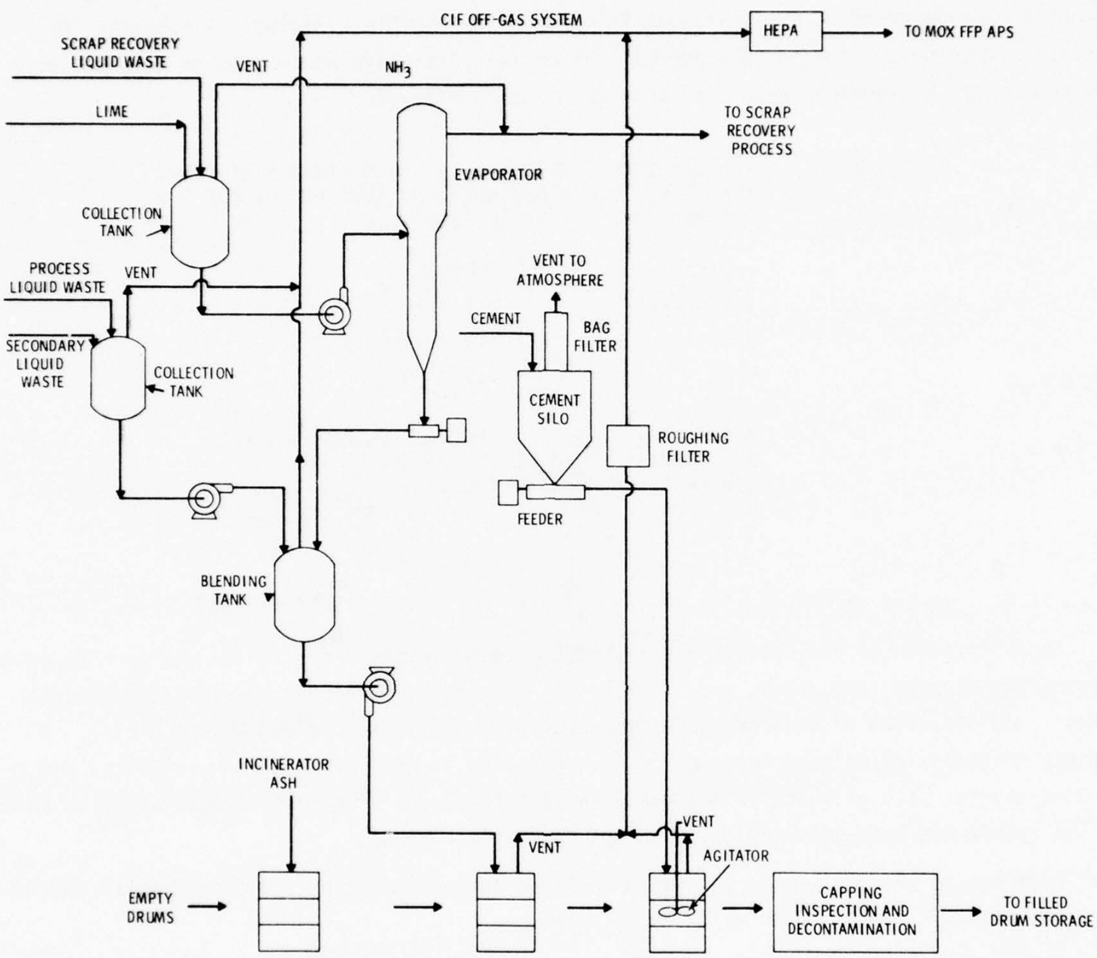


FIGURE 6.2.4-2. Process Flow Diagram for Cement Immobilization at the MOX FFP

Water used during construction is estimated to be 3×10^3 m^3. Withdrawal of this amount of water from the R River, described in the reference environment with an average flow of 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period wells can probably supply the required amount of water without consequence.

Materials committed for construction of the cement immobilization facility are:

Steel	350 MT
Copper	4 MT
Lumber	100 m^3
Concrete	1800 m^3

Energy resources committed for construction are:

Propane	25 m^3
Diesel fuel	260 m^3
Gasoline	200 m^2
Electricity	
Peak demand	300 kWh
Total consumption	200,000 kWh

Except for concrete and lumber, these quantities represent about 7% of the amount required for construction of the MOX FFP. Concrete and lumber requirements are about 15% of those needed for the MOX FFP.

Manpower requirements for construction of the cement immobilization facility amount to 120 man-yr, which will be integrated with labor schedules for the MOX FFP.

No additional transportation requirements have been identified beyond those for the MOX FFP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the cement immobilization facility will be indistinguishable from those resulting from construction of the MOX FFP. Similarly, effects on water quality, water use, and land use will be indistinguishable.

Ecological Effects. There will be no construction impacts for the cement immobilization facility apart from those of the reference MOX FFP. Land area requirements are 520 m^2 and are included with those of the MOX FFP. Water used during the 3.5-year construction period of the entire MOX FFP is approximately 4.9×10^4 m^3; it will be supplied by the R River at the reference site. This amounts to less than the 0.01% of the river low flow and will not have an impact on the river biota. Since the construction water used for the cement immobilization facility is only a small percentage of that required for the entire MOX FFP, no ecological impacts are anticipated.

Environmental Effects Related to Facility Operation. Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the cement immobilization facility are given in Table 6.2.4-12.

Process Effluents. Nonradioactive materials released will be limited to 0.036 MT/yr of cement dust.

Operation of the cement immobilization process at the MOX plant will generate waste heat. The amount of heat generated, 1.2×10^5 MJ/yr (660 hr of operation), will be released principally to the atmosphere via the facility cooling tower.

Table 6.2.4-13 shows the amounts of radioactive materials that reach the biosphere after leaving the cement immobilization system and passing through the reference MOX FFP atmospheric protection system. The radionuclides listed are those that will contribute at least 1% to the

TABLE 6.2.4-12. Utilities and Materials Required for Planned Operation of the MOX FFP Cement Immobilization Facility

Resource	Average Annual Use
Electricity, kWh	1.5×10^4
Water, m^3	6.1×10^1
Lime, MT	6.3
Cement, MT	3.6×10^2
Barrels (55 gal-drums)	1.6×10^3
Steam, kg	1.8×10^4
Manpower (routine), man-yr	1.2

TABLE 6.2.4-13. Annual Releases of Radionuclides to the Atmosphere from the Cement Immobilization Facility at the MOX FFP

Radionuclide	Amount Released, Ci (with Incineration)
^{238}Pu	9.4×10^{-9}
^{239}Pu	6.4×10^{-10}
^{240}Pu	1.3×10^{-9}
^{241}Pu	2.8×10^{-7}
^{241}Am	2.3×10^{-8}

total dose to a given organ from any pathway to man or that are otherwise of interest. The radionuclides are entrained in air derived from process off-gas. The total air flow through the process is estimated to be less than 3×10^{-4} m^3/sec. The total flow of air through the MOX FFP is about 3.3 m^3/sec.

There are no planned releases of radioactive material to the biosphere via liquid effluent streams.

Physical, Chemical, and Thermal Effects. Atmospheric effects resulting from operation of the cement immobilization facility will be limited to air quality impacts resulting from emission of cement dust. The annual average and maximum ground level concentrations of cement dust were calculated to be 3.5×10^{-4} and 5.1×10^{-4} $\mu g/m^3$ respectively. Considering the cement dust as a suspended particulate, an applicable Federal air quality standard would be 75 $\mu g/m^3$.(3) Since releases will be five orders of magnitude below these standards, no physical effects are anticipated. Because the 1.2×10^5 MJ/yr of heat generated by this process is small* when compared with the facility cooling system, the atmospheric impacts resulting from operation of this facility are judged to be insignificant compared with MOX FFP impacts.

* 1.2×10^5 MJ/yr is comparable to the energy consumed in burning forty 100-W light bulbs for one year.

The cement immobilization facility will contribute about 59 m^3/yr to cooling tower makeup water requirements; however, this amount is insignificant. There is no direct ground disposal of liquid or solid wastes from the cement immobilization facility; therefore, no effects are predicted.

Radiological Effects. Doses to individuals in the vicinity of the MOX FFP cement immobilization facility were calculated based on the releases of radionuclides listed in Table 6.2.4-13; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the cement immobilization facility, the only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.2.4-14. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 6.2.4-14. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the Cement Immobilization Facility at the MOX FFP (rem)[a]

Pathway	Total Body	Thyroid (child)	Thyroid	Lung	Bone
Air submersion	4.3×10^{-17}	4.3×10^{-17}	4.3×10^{-17}	4.3×10^{-17}	4.3×10^{-17}
Inhalation	9.1×10^{-12}			7.9×10^{-10}	1.6×10^{-10}
Ingestion	5.0×10^{-15}				9.7×10^{-14}
Total	9.1×10^{-12}	4.3×10^{-17}	4.3×10^{-17}	7.9×10^{-10}	1.6×10^{-10}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.
a. After 30 years of release and accumulation in the environment.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 6.2.4-15 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 2.7×10^{-7} man-rem received from process sources as given in Table 6.2.4-15.

The annual total-body dose to the work force associated with the cement immobilization facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 5 man-rem. Table 6.2.4-16 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 6.2.4-15. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Cement Immobilization Facility at the MOX FFP (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.1×10^{-12}	1.1×10^{-12}	1.1×10^{-12}	1.1×10^{-12}
Inhalation	2.7×10^{-7}		2.0×10^{-5}	4.2×10^{-6}
Ingestion	5.5×10^{-11}			1.1×10^{-9}
Total	2.7×10^{-7}	1.1×10^{-12}	2.0×10^{-5}	4.2×10^{-6}

a. After 30 years of release and accumulation in the environment.

TABLE 6.2.4-16. Summary of Annual Total-Body Doses Received from Operation of the MOX FFP Cement Immobilization Facility and from Naturally Occurring Sources

	Dose, man-rem
Cement immobilization facility	
Process work force (30 yr)	5
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.2.4-17 and 6.2.4-18 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.2.4-19. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with <0.001 man-rem received from operation of the reference facility.

TABLE 6.2.4-17. 70-Year Dose to the Maximum Individual from Gaseous Effluents Released by the Cement Immobilization Facility at the MOX FFP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	1.3×10^{-15}	1.3×10^{-15}	1.3×10^{-15}	1.3×10^{-15}
Inhalation	6.7×10^{-9}		4.4×10^{-8}	1.2×10^{-7}
Ingestion	1.1×10^{-11}			2.2×10^{-10}
Total	6.7×10^{-9}	1.3×10^{-15}	4.4×10^{-8}	1.2×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.
a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.2.4-18. 70-Year Dose to the Population (within 80 km) from Gaseous Effluents Released by the Cement Immobilization Facility at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.4×10^{-11}	3.4×10^{-11}	3.4×10^{-11}	3.4×10^{-11}
Inhalation	1.7×10^{-4}		1.1×10^{-3}	3.0×10^{-3}
Ingestion	3.2×10^{-7}			1.1×10^{-5}
Total	1.7×10^{-4}	3.4×10^{-11}	1.1×10^{-3}	3.0×10^{-3}

TABLE 6.2.4-19. Summary of 70-Year Total-Body Doses Received from Operation of the MOX FFP Cement Immobilization Facility and from Naturally Occurring Sources

	Dose, man-rem
Cement immobilization facility	
Process work force (30 yr)	150
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. No adverse impacts are expected from routine operation of the cement immobilization facility. Nonradioactive chemicals that are potentially harmful to terrestrial plants and animals will not be released to the environment.

About 1.2×10^5 MJ/yr of heat will be released to the atmosphere during operation of the cement immobilization facility. Cement dust will also be discharged to the air. Annual average ground level concentrations will be 8.5×10^{-4} $\mu g/m^3$. The corresponding deposition rate near the MOX FFP fenceline will be 200 $\mu g/m^2$-yr. The air concentrations of cement are a small fraction of the particulate load in natural aerosols — 60 to 220 $\mu g/m^3$ and 10 to 60 $\mu g/m^3$ for urban and nonurban areas respectively. Federal air quality standard for particulates suspended in air is 75 $\mu g/m^3$. The small quantity of heat and dust discharged by the facility will have a negligible impact on terrestrial ecosystems.

During normal operation, 61 m^3/yr of water will be needed. It will be supplied from the R River near the reference site and represents less than 0.01% of the minimum river flow. No ecological impacts will result from removal of this quantity of water. No liquid effluents will be discharged to the environment.

Environmental Effects Related to Postulated Accidents. A number of minor accidents associated with cement immobilization were identified that would be expected to lead to releases of radioactive material. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
4.7.1	Overfill waste drum
4.7.2	Drum filling control valve failure
4.7.3	Drum fill level detector instrument failure
4.7.4	Container drop or rupture
4.7.5	Leakage in waste in transfer line

Based on the anticipated releases of these minor accidents weighted by their expected frequency of occurrence, an average annual release was postulated. The estimated quantities of radionuclides released to the atmosphere are presented in Table 6.2.4-20.

TABLE 6.2.4-20. Radionuclides Annual Release to the Atmosphere from Minor Accidents at the Cement Immobilization Facility at the MOX FFP

Radionuclide	Release, Ci
^{238}Pu	9.1×10^{-13}
^{239}Pu	6.2×10^{-14}
^{240}Pu	1.2×10^{-13}
^{241}Pu	2.8×10^{-11}
^{241}Am	2.3×10^{-13}

Annual doses and 70-year dose commitments to the maximum individual and the regional population were calculated for these releases using average annual dispersion factors. In no case was the resulting dose greater than 2×10^{-12} rem for any individual dose and most often was several orders of magnitude less and does not constitute a radiological impact. These doses are about five orders of magnitude lower than dose received from routine operation.

No moderate or severe accidents were postulated within the design basis of the facility and no non-design basis accidents were considered. With no radioactive releases from accidents, no ecological effects will occur.

6.2.4.3 Comparison of Environmental Effects Between Alternatives for Waste Immobilization at the MOX FFP

Resource commitments, energy requirements, and effluent releases have been compared for the non-high-level transuranic waste immobilization facilities at the MOX FFP. During construction, approximately equal commitments of material and energy resources will be required for both bitumen and cement immobilization facilities. Resource commitments are not significant in either case and uncertainties in estimates could account for some differences. No

significant differences are anticipated in the chemical, thermal, or ecological effects related to construction. Table 6.2.4-21 summarizes resource commitments of construction.

TABLE 6.2.4-21. Comparison of Resource Commitments for Construction of Alternative Waste Immobilization Facilities at a MOX FFP

Resource	Bitumen Immobilization Facility	Cement Immobilization Facility
Land, m^2	4.5×10^2	5.2×10^2
Water, m^3	3.0×10^3	3.0×10^3
Materials		
Concrete, m^3	1.5×10^3	1.8×10^3
Steel, MT	3.5×10^2	3.5×10^2
Copper, MT	5	4
Lumber, m^3	1.0×10^2	1.0×10^2
Energy		
Propane, m^3	2.5×10^1	2.5×10^1
Diesel fuel, m^3	2.7×10^2	2.6×10^2
Gasoline, m^3	2.0×10^2	2.0×10^2
Electricity, kWh	2.0×10^5	2.0×10^5
Manpower, man-yr	1.2×10^2	1.2×10^2

Materials used during facility operation are different (bitumen versus cement) but consist of about the same quantities for both facilities. The cement immobilization process would add about 0.036 MT/yr of cement dust to the atmosphere, whereas bitumen would be released from the bitumen immobilization process. Airborne bitumen can cause strong, unpleasant odors near the facility. However, procedures can be implemented such that release of the material from the MOX FFP stack and dispersion in the atmosphere will reduce the odor to acceptable levels at the site boundary. Table 6.2.4-22 summarizes nonradiological aspects of immobilization facility operation.

Releases of radioactive material from both processes are the same. The 70-year total-body dose to the maximum individual from either process is 3.2×10^{-8} rem and is not considered to constitute a radiological impact. The 70-year population dose for either process is 8.2×10^{-4} man-rem. During routine operation, radiological impacts will be the same using either process. The population dose received from naturally occuring sources for the same peiod is 1.4×10^7 man-rem.

The overall environmental effects of the two processes are similar. However, the ease of handling, lack of waste heat, and low probability of fire and other accidents during operation and storage appear to be noteworthy advantages to the reference cement immobilization process.

TABLE 6.2.4-22. Comparison of Nonradiological Aspects of Operating Alternative Waste Immobilization Facilities (with Incineration) at the MOX FFP

	Annual Quantity	
	Bitumen Immobilization Facility	Cement Immobilization Facility
Resource		
Water consumed, m^3	8.2×10^2	6.1×10^1
Materials		
Stainless steel drums (55 gal)	5.3×10^2	1.6×10^3
Portland cement, MT		3.7×10^2
Bitumen, MT	8.5×10^2	
Lime, MT		5.9
Electricity, kWh	2.2×10^5	1.5×10^4
Manpower, man-yr	2.3	1.2
Nonradioactive effluents released to atmosphere		
Bitumen, MT	Not quantified	
Cement dust, MT		0.036
Heat released to atmosphere, MJ	1.7×10^6	1.2×10^5

REFERENCES FOR SECTION 6.2.4

1. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA 76-43, Energy Research and Development Administration, Washington, DC, May 1976.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

3. A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

6.3 ON-PLANT INTERIM STORAGE OF NON-HIGH-LEVEL TRANSURANIC WASTES AT A MOX-FFP

6.3 ON-PLANT INTERIM STORAGE OF NON-HIGH-LEVEL TRANSURANIC WASTES AT A MOX FFP

During operation of the mixed-oxide fuel fabrication plant (MOX FFP) non-high-level wastes are generated. Such wastes include only low-level wastes; there are no intermediate-level wastes produced at the MOX FFP. The low-level wastes are packaged as transuranic wastes in 55-gal drums and in steel boxes of dimensions 1.2 x 1.8 x 1.8 m. Facilities may be required for interim storage of solidified wastes in the event a Federal repository is not available to accept these wastes at the time they are generated. Indoor and outdoor facilities are considered for interim storage of non-high-level transuranic wastes from operation of the MOX FFP.

6.3.1 Outdoor Surface Storage of Low-Level Transuranic (DOE/ET-0028 Sec. 5.3.1)

The reference outdoor surface storage facility is designed to store solid low-level transuranic wastes contained in 55-gal drums and steel boxes on an above-ground asphalt slab. The drums and boxes are ultimately covered by an earth fill for weather protection. Alternatives to this concept include facilities with different methods for providing weather protection and facilities with no weather protection.

Outdoor surface storage facilities at the MOX FFP will have a capacity to store wastes from the first five years of operation (10,000 55-gal drums). Figure 6.3.1-1 is a flow diagram showing operation, materials, and equipment involved in the storage concept. Table 6.3.1-1 shows the annual waste flows to the storage facility at the reference MOX FFP.

6.3.1.1 Environmental Effects Related to Facility Construction

Site preparation and construction of the low-level transuranic waste outdoor storage facility may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for estimating the effects of construction.

Resource Commitments. The outdoor surface storage facility for low-level transuranic waste will be located at the reference MOX FFP; therefore, the effects of facility construction will be largely inseparable from those of the main plant. The storage facility will occupy approximately 0.24 ha or about 0.06% of the area required by the MOX FFP. Since this land commitment is included in that required for the MOX FFP, no separate analysis of land use was made.

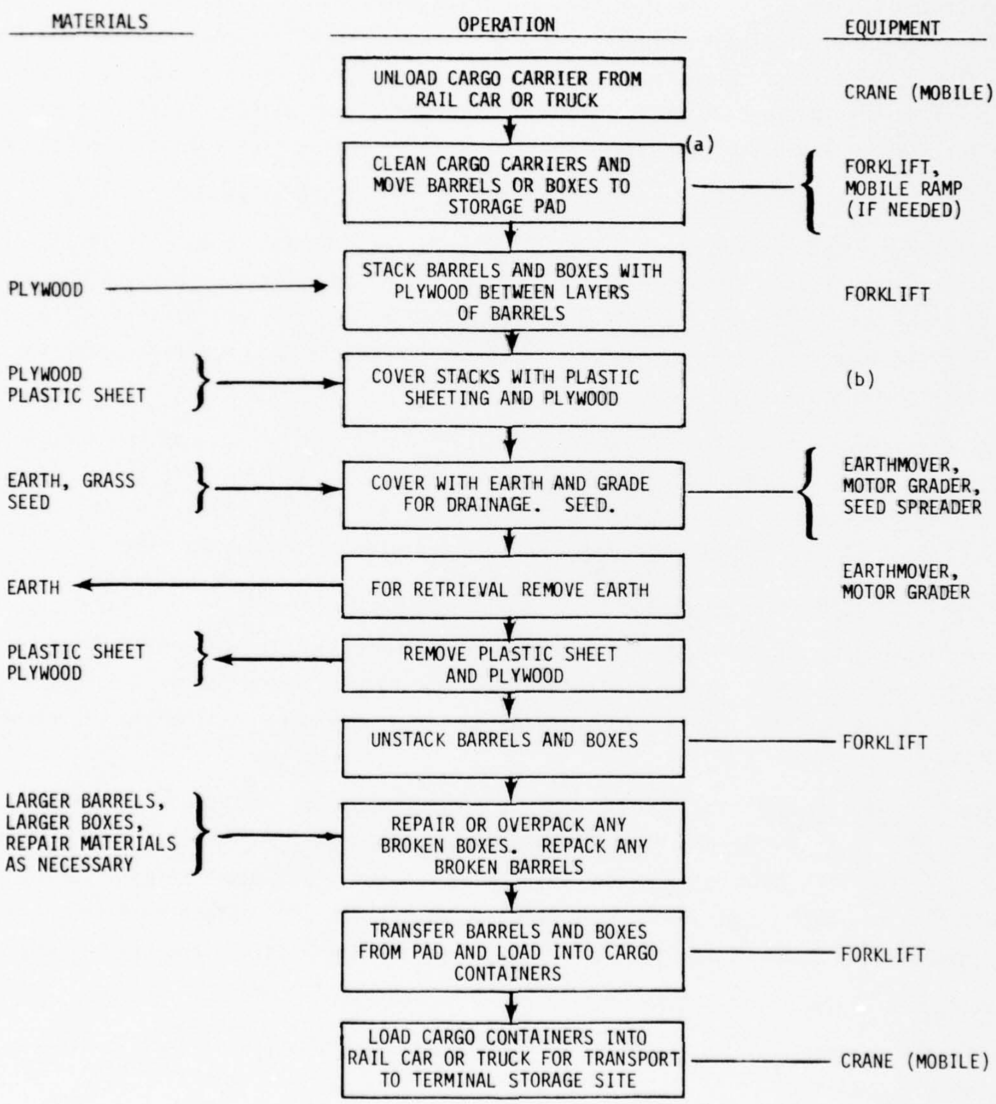
Water used during construction will be approximately 100 m^3.

Materials committed to construction of the outdoor surface storage facility (basic 10,000 drum storage module) are:

Steel	35 MT
Copper	0.9 MT
Lumber	10 m^3
Concrete	75 m^3

Energy resources used during construction are:

Propane	0.7 m^3
Diesel fuel	7.0 m^3
Gasoline	5.0 m^3
Electricity	negligible (<10,000 kWh)



a. Alternatively, instead of opening the cargo carrier at rail side the cargo carrier may be transferred to the storage pad and opened there. This is preferable procedure if the cargo carrier arrives at the site by truck--the truck can be driven directly to the pad for unloading.

b. Where no equipment is indicated the operation is done manually. Where equipment is shown, the operation may be done entirely with equipment or by both manual and equipment operations.

FIGURE 6.3.1-1. Flow Diagram for Handling Low-Level Transuranic Wastes at the Outdoor Surface Storage Facility at the MOX FFP

TABLE 6.3.1-1. Annual Flow of Low-Level Transuranic Wastes to Storage at the MOX FFP

Years	Equivalent 55-gal Drums[(a)]
1	800
2	1600
3 to 5	2400

a. The number of drums includes 55-gal drums and boxes that hold the equivalent of twelve 55-gal drums.

Manpower requirements for construction of the outdoor surface storage facility will amount to 4.5 man-yr, which will likely be integrated with labor schedules for the MOX FFP.

No additional requirements for transportation or for the site are needed beyond those identified for the MOX FFP.

Physical and Chemical Effects. The 100 m^3 of water required during facility construction will be supplied from the R River near the reference site. This amount of water is less than 0.01% of the average annual river flow and its removal will not interfere with other downstream water uses. Excavation for the waste storage area and storm water retention ponds and filling for the earth berm surrounding the storage area is not expected to affect groundwater movement. There may be some water erosion of the area cleared for construction, but this can be controlled by ditching and land contouring. No substantial siltation of nearby surface waters is expected during construction activities.

There will be some releases of air pollutants through the burning of fuel by construction equipment and the generation of fugitive dust by grading and excavation. These will be small compared with those of the overall MOX FFP construction and are not expected to produce significant environmental effects. In general, the environmental effects of facility construction related to water and land use cannot be separated from the effects of MOX FFP construction.

Ecological Effects. No ecological impacts of facility construction beyond those of the overall MOX FFP are expected. Destruction of vegetation and displacement of birds and animals will be a small part of the impact produced by overall MOX FFP construction. No unusual or unique environmental effects have been identified.

Water used during construction will be supplied from the common MOX FFP water supply and will be an insignificant fraction of the R River flow from which the water is withdrawn. No ecological impacts on the river ecosystem are expected from water use during construction of the storage facility.

Air pollutants generated during construction by the burning of fossil fuels and the generation of dust will result in insignificant pollutant concentrations in air, and no ecological impacts of any consequence will result.

6.3.1.2 Environmental Effects Related to Facility Operation

Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required for operation of the outdoor surface storage facility for low-level transuranic wastes are given in Table 6.3.1-2.

TABLE 6.3.1-2. Utilities and Materials Required for Operating the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP

Resource	Average Annual Use
Electricity, MWh	50
Water, m^3	45
Plastic sheets, m^2	450
Plywood (1/2-in.), m^2	700
Diesel fuel, m^3	3.8
Manpower, man-yr	6.5×10^{-1}

Process Effluents. No radioactive materials will be released to the biosphere during normal operation of the storage facility.

Combustion of about 4 m^3 of diesel fuel by various equipment used for storage and handling operations will release small quantities of pollutants to the atmosphere.[1] The amounts of these combustion products will be a small fraction of the overall MOX FFP.

There are no planned direct releases of nonradioactive liquid or solid wastes to the ground or to surface or groundwaters from operation of the outdoor surface storage facility. All liquid and solid waste disposal will be part of the overall MOX FFP operation. Sediment runoff may occur during backfilling of the stored drums with a layer of soil 0.9 m thick. Drainage runoff may need to be diverted into retention basins prior to release to the environment.

Physical, Chemical, and Thermal Effects. Atmospheric effects from operation of the outdoor surface storage facility will be limited to air quality effects resulting from emission of nonradioactive pollutants from equipment. Annual average and maximum ground level concentrations of pollutants released by equipment were computed using annual average dispersion factors ($\overline{\chi}/Q'$) for a ground level release in the reference environment. These fenceline concentrations are several orders of magnitude below existing standards and are not expected to cause any degradation of air quality. Deposition of these pollutants on surfaces near the facility will not cause any physical or chemical effects.

With no release of nonradioactive liquid effluents to the environment, no effects will result from facility operation.

Radiological Effects. No radioactive materials will be released during operation of the outdoor surface storage facility; therefore, no environmental effects will result.

Ecological Effects. No ecological effects of any significance will result during normal operation of the outdoor surface storage facility. The air pollutants released during the burning of diesel fuel will have an insignificant ecological effect. Water use and discharges from sanitary and sewer systems will have an insignificant effect on the environment.

6.3.1.3 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with operation of the outdoor surface storage facility for low-level transuranic wastes would be expected to lead to releases of radioactive material. The scenarios for these accidents are provided in DOE/ET-0028[2] and the accidents are as follows:

Accident Number	Description
5.3.1	Mechanical breach of barrel
5.3.2	Dislodge of surface contamination
5.3.3	Overpressure of containers
5.3.4	Rust through of steel containers

Based on anticipated releases of these minor accidents weighted by their expected frequency of occurrence, an average annual release of waste was determined. The material released is equivalent to 2.5×10^{-5} of the inventory of 1-year-old waste in 0.47 barrel breaches of solidified low-level transuranic wastes. The radionuclides released are given in Table 6.3.1-3.

TABLE 6.3.1-3. Estimated Annual Releases of Radionuclides to the Atmosphere from Minor Accidents in the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP

Radionuclide	Release, Ci
^{238}Pu	1.1×10^{-4}
^{239}Pu	7.8×10^{-6}
^{240}Pu	1.6×10^{-5}
^{241}Pu	3.5×10^{-3}
^{241}Am	2.9×10^{-5}

Annual doses for the maximum individual and the regional population were calculated and are given in Tables 6.3.1-4 and 6.3.1-5 respectively. Seventy-year cumulative doses were calculated for these two groups and are given in Tables 6.3.1-6 and 6.3.1-7 respectively.

TABLE 6.3.1-4. Annual Doses to the Maximum Individual from Minor Accidents at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (rem)

Pathway	Total Body	Thyroid (child)(a)	Thyroid(b)	Lung	Bone
Air submersion	3.7×10^{-13}	3.7×10^{-13}	3.7×10^{-13}	3.7×10^{-13}	3.7×10^{-13}
Inhalation	3.2×10^{-7}			2.0×10^{-5}	7.2×10^{-6}
Ingestion	2.2×10^{-11}				7.8×10^{-10}
Total	3.2×10^{-7}	3.7×10^{-13}	3.7×10^{-13}	2.0×10^{-5}	7.2×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1150 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.9×10^{-6} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk/day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.3.1-5. Annual Doses to the Population (within 80 km) from Minor Accidents at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.2×10^{-9}	3.2×10^{-9}	3.2×10^{-9}	3.2×10^{-9}
Inhalation	2.7×10^{-3}		1.7×10^{-1}	6.0×10^{-2}
Ingestion	2.4×10^{-7}			8.7×10^{-6}
Total	2.7×10^{-3}	3.2×10^{-9}	1.7×10^{-1}	6.0×10^{-2}

TABLE 6.3.1-6. Seventy-Year Doses to the Maximum Individual from Minor Accidents at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (rem)

Pathway	Total Body	Thyroid(a)	Lung	Bone
Air submersion	1.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}
Inhalation	2.1×10^{-4}		1.1×10^{-3}	4.4×10^{-3}
Ingestion	3.5×10^{-8}			1.2×10^{-6}
Total	2.1×10^{-4}	1.1×10^{-11}	1.1×10^{-3}	4.4×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 1150 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.9×10^{-6} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The most serious accidents postulated to involve radioactive materials in amounts larger than those released by minor accidents are classified as a moderate accident and are listed below:

Accident Number	Description
5.3.5	Fire in storage stack
5.3.6	Tornado strike during stacking operation

TABLE 6.3.1-7. Seventy-Year Doses to the Population (within 80 km) from Minor Accidents at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	9.5×10^{-8}	9.5×10^{-8}	9.5×10^{-8}	9.5×10^{-8}
Inhalation	1.8		9.7	3.7×10^{1}
Ingestion	3.9×10^{-4}			1.4×10^{-2}
Total	1.8	9.5×10^{-8}	9.7	3.7×10^{1}

Accident 5.3.6 results in the larger release of radioactive material. For this accident, three boxes containing contaminated failed equipment are ruptured during a tornado strike while the containers are being stacked; 0.001 of their contents is entrained in the atmosphere. The estimated kinds and amounts of radionuclides released to the environment are given in Table 6.3.1-8. Radionuclides that contribute 1% or more to the total dose to a given organ from any pathway are listed.

TABLE 6.3.1-8. Radionuclides Released to the Atmosphere During a Tornado at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP

Radionuclide	Release, Ci
^{238}Pu	2.3×10^{-2}
^{239}Pu	1.6×10^{-3}
^{241}Pu	7.1×10^{-1}
^{241}Am	1.2×10^{-3}

The 1-year and 70-year dose commitments to the maximum individual from the release of these radioactive materials are given in Table 6.3.1-9.

Ecological Effects. No ecological effects would be expected from the release of small quantities of materials identified in the postulated accidents.

TABLE 6.3.1-9. Doses Received by the Maximum Individual from a Moderate Accident at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes at the MOX FFP

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		One-Year Dose, rem			
Air submersion	3.1×10^{-14}	1.7×10^{-14}	1.7×10^{-14}	1.7×10^{-14}	1.7×10^{-14}
Inhalation		3.2×10^{-8}		2.2×10^{-6}	7.4×10^{-7}
Total	3.1×10^{-14}	3.2×10^{-8}	1.7×10^{-14}	2.2×10^{-6}	7.4×10^{-7}
		70-Year Dose, rem			
Air submersion	3.2×10^{-14}	1.7×10^{-14}	1.7×10^{-14}	1.7×10^{-14}	1.7×10^{-14}
Inhalation		1.0×10^{-6}		5.4×10^{-6}	2.2×10^{-5}
Total	3.2×10^{-14}	1.0×10^{-6}	1.7×10^{-14}	5.4×10^{-6}	2.2×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location 1150 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.9×10^{-6} sec/m^3.

REFERENCES FOR SECTION 6.3.1

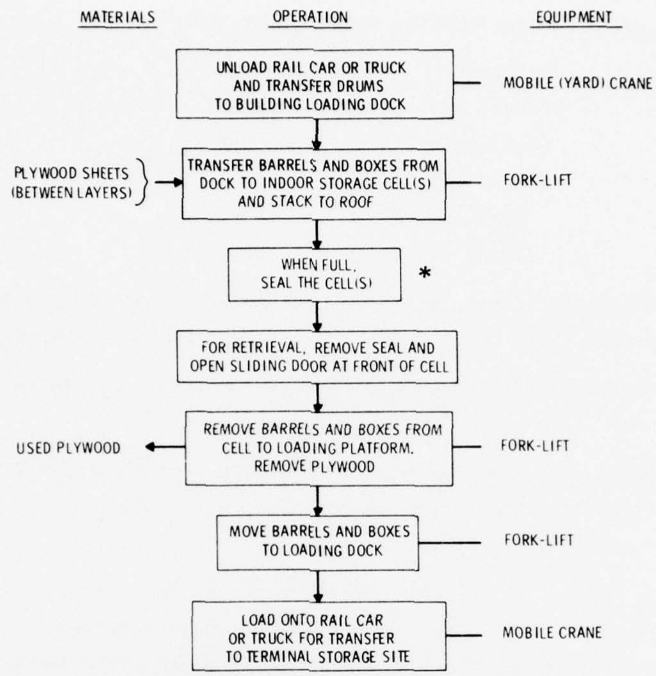
1. Compilation of Air Pollutant Emission Factors, AP-42, Environmental Protection Agency, Research Triangle Park, NC, April 1973.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

6.3.2 Indoor Unshielded Storage of Low-Level Transuranic Wastes at the MOX FFP (DOE/ET-0028 Sec. 5.3.2)

The indoor unshielded interim storage facility is a modular thin-slab-reinforced concrete structure for storage of low-level transuranic wastes contained in 55-gal drums or steel boxes. Alternatives involve variations in design of the structure and in building materials. This design was selected as a technically viable representative of the indoor unshielded storage concept.

Indoor unshielded storage facilities at the reference MOX FFP will have a capacity to store low-level transuranic wastes generated during the first five years operation (10,000 55-gal drums). Figure 6.3.2-1 shows the operations, materials, and equipment used for this storage concept. The design of two typical cells for indoor unshielded storage with a capacity for 8400 55-gal drums of low-level transuranic wastes is given in Section 5.3.2 of DOE/ET-0028.[1] The desired capacity for the facility is obtained by building multiples of these modules. Figure 6.3.2-1 lists the equipment required for this storage concept.



* WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 6.3.2-1. Flow Diagram for Handling Low-Level Transuranic Wastes Received at the MOX FFP Indoor Unshielded Storage Facility

6.3.2.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and construction of the indoor unshielded storage facility may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The indoor unshielded storage facility (2.5 cells) will occupy approximately 0.12 ha and will have a capacity of 10,000 drums. This land commitment is included with that of the MOX FFP, consequently no separate impact analysis is deemed necessary.

Water used during construction will be approximately 4.8 x 10^2 m^3 for the 10,000-drum facility.

Materials committed for construction of the indoor unshielded storage facility (10,000 drum storage module) are:

Steel	60 MT
Lumber	10 m^3
Concrete	500 m^3

Energy resources used during facility construction are:

Propane	4 m^3
Diesel fuel	40 m^3
Gasoline	20 m^3
Electricity	
Peak demand	30 kW
Total consumption	20,000 kWh

Manpower requirements for construction of the indoor unshielded storage facility amount to 12.5 man-yr, which will likely be integrated with labor schedules for the MOX FFP.

No separate transportation or site requirements for this facility have been identified beyond those for the MOX FFP.

Physical and Chemical Effects. Construction of the indoor unshielded storage facility requires the diversion of about 400 m^3 of water. This water use will not have a significant impact on downstream water uses.

The use of about 1200 m^2 of land for the indoor unshielded storage facility will not have a significant impact on local land use. Moreover, environmental effects of the facility construction related to water and land use cannot be separated from the effects of the overall MOX FFP construction.

The burning of approximately 60 m^3 of gasoline and diesel fuel will release pollutants to the atmosphere. The levels of hydrocarbons, carbon monoxide, particulates, and oxides of nitrogen and sulfur will be well below the limits specified in the Federal air quality standards. There will also be some generation of dust by the construction activities. These pollutants will be largely confined to the area occupied by the overall MOX FFP complex.

Ecological Effects. No ecological impacts of facility construction beyond those of the overall MOX FFP are expected. Destruction of vegetation and displacement of birds and animals will be a small part of the effects caused by MOX FFP construction. No separate or additional transportation requirements for the indoor unshielded storage facility are expected, nor have any unique or unusual environmental effects been identified that would result from construction of the facility.

Water used during the construction period will be supplied by the common MOX FFP water supply. This supply obtains water from the R River, and the volume of water required during construction of this facility represents an insignificant fraction of the river flow. No ecological impacts on the river's ecosystems are expected to result from this volume of water removal.

Only about 60 m^3 of fossil fuel will be burned during construction of the facility. Emissions from the combustion of these fuels will contribute an insignificant amount of effluents to the atmosphere. Thus, no identifiable impact on terrestrial organisms is expected to result from emissions caused by fuel combustion.

6.3.2.2 Environmental Effects Related to Facility Operation

Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of facility operation.

Resource Commitments. The resources required for planned operation of the indoor unshielded storage facility for low-level transuranic wastes are given in Table 6.3.2-1. The use of these resources is judged to have an insignificant effect on the environment.

TABLE 6.3.2-1. Utilities and Materials Required for Operation of the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes at the MOX FFP

Resource	Average Annual Use
Electricity, MWh	50
Diesel fuel, m^3	1.9
Water, m^3	38
Lumber (1/2-in. plywood), m^2	900
Manpower, man-yr	0.65

Process Effluents. During normal operation of the facility, no radioactive materials will be released to the environment.

Combustion of about 2 m^3/yr of diesel fuel by trucks and other equipment will release small quantities of pollutants to the atmosphere. The amounts of these combustion products will be a small fraction of those released by the MOX FFP.

There will be no direct releases of radioactive or nonradioactive liquid or solid wastes to land, surface, or groundwaters from the indoor unshielded storage operation. All liquid and solid waste disposal will be part of the overall MOX FFP operation.

Physical, Chemical, and Thermal Effects. The release of small amounts of fossil fuel combustion products to the atmosphere will be within Federal air quality limits and will contribute only a small fraction of those products released from the overall operation of the MOX FFP. There are no planned direct releases of liquid or solid wastes to water or land; therefore, there will be no effects.

Radiological Effects. No radioactive materials will be released to the biosphere from normal operation of the indoor waste storage facility; therefore no radiological effects will result.

Ecological Effects. Normal operation of the indoor unshielded storage facility will result in no significant ecological effects. No unique or unusual effluents are expected to be released during normal operation of this facility.

Water used for sanitary purposes will be supplied from the common MOX FFP water supply system. This quantity represents a small fraction of the flow of the R River and therefore,

no ecological impact on the river ecosystem is expected to result. A fraction of the water used for sanitary needs will be discharged to the common MOX FFP sewer system. No ecological impact will result from this discharge.

The land area occupied by this facility for the temporary storage of radioactive wastes will be unavailable for wildlife production, agriculture, or other uses for the life of the facility. However, since the facility is located within the MOX FFP, the land would be unavailable for such uses even if the waste storage facility were not built and operated.

6.3.2.3 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with the indoor unshielded storage facility for low-level transuranic wastes at the MOX FFP would be expected to lead to releases of radioactive material. The accidents are listed below and are described in detail in Section 5.3.2 of DOE/ET-0028.[1]

Accident Number	Description
5.3.1	Mechanical breach of barrel
5.3.2	Dislodge of surface contamination
5.3.3	Overpressure of container
5.3.4	Rust through of steel container
5.3.7	Fire in storage rack

Based on anticipated releases of these minor accidents weighted by their expected frequency of occurrence, an average annual release of waste was determined. The material released is 2.5×10^{-5} of the 1-year-old waste in 0.47 barrel breaches of solidified low-level transuranic waste. The radionuclides released are given in Table 6.3.2-2. (This accident and its consequences are the same as those described in Section 6.3.1.)

Annual doses were calculated for the maximum individual and the regional population and are given in Tables 6.3.2-3 and 6.3.2-4 respectively. Seventy-year cumulative doses were also calculated for these two groups and are given in Tables 6.3.2-5 and 6.3.2-6 respectively.

No discernible ecological effects are expected from the accidental releases.

TABLE 6.3.2-2. Estimated Annual Releases of Radionuclides to the Atmosphere from Minor Accidents in the Indoor Shielded Storage Facility for Low-Level Transuranic Wastes at the MOX FFP

Radionuclide	Releases, Ci
^{238}Pu	1.1×10^{-4}
^{239}Pu	7.8×10^{-6}
^{240}Pu	1.6×10^{-5}
^{241}Pu	3.5×10^{-3}
^{241}Am	2.9×10^{-5}

TABLE 6.3.2-3. Annual Doses to the Maximum Individual from Minor Accidents in the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (rem)

Pathway	Total Body	Thyroid (child)[(a)]	Thyroid[(b)]	Lung	Bone
Air submersion	3.7×10^{-13}	3.7×10^{-13}	3.7×10^{-13}	3.7×10^{-13}	3.7×10^{-13}
Inhalation	3.2×10^{-7}			2.0×10^{-5}	7.2×10^{-6}
Ingestion	2.2×10^{-11}				7.8×10^{-10}
Total	3.2×10^{-7}	3.7×10^{-13}	3.7×10^{-13}	2.0×10^{-5}	7.2×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1150 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.9×10^{-6} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk/day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season 4 months/yr).

TABLE 6.3.2-4. Annual Doses to the Population (within 80 km) from Minor Accidents in the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.2×10^{-9}	3.2×10^{-9}	3.2×10^{-9}	3.2×10^{-9}
Inhalation	2.7×10^{-3}		1.7×10^{-1}	6.0×10^{-2}
Ingestion	2.4×10^{-7}			8.7×10^{-6}
Total	2.7×10^{-3}	3.2×10^{-9}	1.7×10^{-1}	6.0×10^{-2}

TABLE 6.3.2-5. 70-Year Doses to the Maximum Individual from Minor Accidents in the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (rem)

Pathway	Total Body	Thyroid[(a)]	Lung	Bone
Air submersion	1.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}
Inhalation	2.1×10^{-4}		1.1×10^{-3}	4.4×10^{-3}
Ingestion	3.5×10^{-8}			1.2×10^{-6}
Total	2.1×10^{-4}	1.1×10^{-11}	1.1×10^{-3}	4.4×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 1150 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.9×10^{-6} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk/day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

TABLE 6.3.2-6. 70-Year Doses to the Population (within 80 km) from Minor Accidents in the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	9.5×10^{-8}	9.5×10^{-8}	9.5×10^{-8}	9.5×10^{-8}
Inhalation	1.8		9.7	3.7×10^{1}
Ingestion	3.9×10^{-4}			1.4×10^{-2}
Total	1.8	9.5×10^{-8}	9.7	3.7×10^{-1}

No accidents thought to involve longer releases of radioactive material were identified. No non-design basis accidents were considered.

REFERENCES FOR SECTION 6.3.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

6.3.3 Comparison of Environmental Effects Between Alternatives for Storing Low-Level Transuranic Wastes at the MOX FFP

Requirements for a low-level transuranic waste storage facility and for the amounts of effluents released from such a facility are based on an estimated capacity of 10,000 55-gal drums, which is judged to be the necessary storage capacity through the year 1990.

Resources required for construction of the storage facility are generally less for the outdoor facility (Table 6.3.3-1). Exceptions are found in the water and land requirements where the indoor unshielded facility is lower by a factor of 2. The resource commitments are not great for either alternative and do not provide a clear basis for choice.

The operational requirements for indoor unshielded storage of low-level transuranic wastes are generally lower than those for outdoor storage (Table 6.3.3-2). Atmospheric release of pollutants is less for the indoor unshielded facility, though it is negligible for both. The releases will lead to concentrations several orders of magnitude below applicable Federal air quality standards. The indoor waste facility also shows an advantage over the outdoor facility in terms of resources needed.

During planned operation no radioactive materials will be released to the environment from either of the low-level transuranic waste storage facilities. There will also be no releases of nonradioactive pollutants to either land or surface waters.

The postulated credible moderate accident (the rupture of waste containers by a tornado and the release of radioactive materials to the biosphere) applies only to the surface waste storage option. The estimated 70-year dose received from this accident will be about 1×10^{-6} rem to the total body of the maximum individual. Radiation doses from minor accidents will be the same for both options and the 70-year cumulative dose will be about 2×10^{-4} rem.

TABLE 6.3.3-1. Comparison of Resources Required for Construction of Alternative Facilities for Storing Low-Level Transuranic Wastes at the MOX FFP (10,000 drum storage module)

Resource	Outdoor Surface Storage	Indoor Unshielded Storage
Manpower, man-yr	4.5	14
Land, m^2	2,400	1,200
Water, m^3	1,000	400
Materials		
Concrete, m^3	75	500
Steel, MT	35	60
Copper, MT	0.9	
Lumber, m^3	10	10
Energy		
Propane, m^3	0.7	4
Diesel fuel, m^3	7.0	40
Gasoline, m^3	5	20
Electricity, kWh	negligible (<10,000)	20,000

TABLE 6.3.3-2. Comparison of Nonradiological Aspects of Operating Alternative Facilities for Storing Low-Level Transuranic Wastes at the MOX FFP

	Outdoor Surface Storage	Indoor Unshielded Storage
Manpower, man-yr/yr	0.65	0.65
Materials		
Plastic sheets, m^2/yr	450	
Diesel fuel, m^3/yr	38	2
Plywood (1/2-in.), m^2/yr		900
Electricity, MWh/yr	50	50

6.4 ALTERNATIVES FOR DECOMMISSIONING A MOX-FFP

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6.4 ALTERNATIVES FOR DECOMMISSIONING A MOX FFP

Two decommissioning modes will be considered in detail for a mixed-oxide fuel fabrication plant (MOX FFP): immediate dismantlement and entombment (hardened safe storage).

For dismantlement, all potentially hazardous amounts of radioactive material are removed from the site to an approved disposal facility. Some nonradioactive portions of the facility may be removed to ensure removal of all radioactive materials.

Entombment prepares the facility to be left in place until all radioactive material has decayed to acceptable levels as established by Federal regulation. Radioactive material in the facility is consolidated in areas of relatively high contamination. Permanent physical barriers are erected between the radioactive material and the environment. A surveillance and environmental monitoring program is established to ensure the continued protection of the public and environment from the radioactive material in the entombed structure.

Since most of the residual contamination in the facility has a relatively long half-life, protective storage is considered as a final decommissioning state. The absence of large amounts of shorter half-life radioactive contamination in the facility provides little incentive to consider delayed dismantlement.

The analysis presented here assumes that facility shutdown activities have been completed when decommissioning begins. Activities assumed to have been carried out prior to decommissioning to shut down the facility include the removal of all product and feed materials; the processing, packaging, and removal of all radioactive wastes generated during facility operations or shutdown activities; the completion of preparations for closeout of special nuclear material accountability requirements; and the removal of hazardous chemicals and flammable materials not required for the decommissioning operations.

6.4.1 Decommissioning of MOX FFP by Dismantlement (DOE/ET-0028 Sec. 8.6.2)

Some aspects of dismantling a MOX FFP may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of dismantling activities.

6.4.1.1 Resource Commitments

The reference MOX FFP site consists of a 400-ha plot, with a 6-ha exclusion area that contains the MOX FFP. Dismantlement allows the MOX FFP site and exclusion area to be released for alternate uses, as the owner desires, after dismantlement is completed.

Water used during dismantling is estimated to be 1.1×10^2 m^3 during chemical decontamination. Withdrawal of this amount of water from the River R, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses. After chemical decontamination is completed, water requirements will be limited to sanitary needs of a work force of 50 people during the remainder of the dismantling process. This would amount to 1×10^4 m^3 of water during the 2-year period of dismantling.

Materials committed for dismantling of the reference MOX FFP are:

Steel shipping containers	4.5×10^2
Paper, wood, plastic	5.0×10^1
Equipment (mostly steel)	1.0×10^2

Energy resources committed for dismantling are:

Electricity	10,000 kWh

Manpower requirements for dismantling operations will amount to 170 man-yr.

6.4.1.2 Process Effluents

During demolition, dismantlement, and site restoration, fugitive dust will be generated. Effluents from operation of heavy equipment will also be produced during these phases of decommissioning. The effects are transitory and confined to the immediate site and site vicinity. Usual preventative procedures such as wetting exposed areas may be required to control dust emissions.

Routine radioactive effluents released during dismantling would be limited to airborne releases. No routine releases to water have been identified. Airborne releases would amount to 700 μg of mixed oxide (about 30 μg of plutonium and 670 μg of uranium) or 2.4×10^{-4} Ci of mixed oxide. Routine atmospheric releases of gases and particulates are summarized in Table 6.4.1-1.

TABLE 6.4.1-1. Radionuclides Released to the Atmosphere During 2-yr Period of Dismantling of the Reference MOX FFP

Radionuclide	Release, Ci
^{238}Pu	1.2×10^{-5}
^{239}Pu	8.8×10^{-7}
^{240}Pu	1.8×10^{-6}
^{241}Pu	2.2×10^{-4}
^{241}Am	7.0×10^{-6}

6.4.1.3 Physical, Chemical, and Thermal Effects

The effects of emissions on ambient air quality will be similar to the impacts computed for construction of a reference facility.[1,2] This analysis indicates that the maximum particulate air concentrations will be about 30 $\mu g/m^3$ occurring in the immediate vicinity of the demolition and restoration activities.

During times other than demolition and site restoration, no noticeable effects on air quality are expected. The pricipal source of effluents released during these periods will be from traffic, which is expected to be less than the traffic during normal plant operations. No effects on air quality exceeding established standards are expected.

6.4.1.4 Radiological Effects

During dismantling of the MOX FFP about 20 m^3 of combustible transuranic wastes will be generated after the waste treatment facilities have been shut down. These wastes will be packaged and shipped to an offsite waste treatment facility where they will be immobilized and sent to a repository.

Doses to individuals in the vicinity of the MOX FFP during dismantling were calculated based on the releases of radionuclides listed in Table 6.4.1-1; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). Exposure pathways to man will exist only for airborne effluents.

The annual dose to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.4.1-2. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 6.4.1-2. *Annual Doses Received by the Maximum Individual During the 2-yr Period of Dismantling of the Reference MOX FFP (rem)*

Pathway	Total Body	Thyroid (child)[(a)]	Thyroid[(b)]	Lung	Bone
Air submersion	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}
Inhalation	6.1×10^{-9}			4.9×10^{-7}	1.2×10^{-7}
Ingestion	2.7×10^{-12}				7.6×10^{-11}
Total	6.1×10^{-9}	1.5×10^{-14}	0	4.9×10^{-7}	1.2×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the site center with the highest annual average dispersion factor (χ/Q') of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 6.4.1-3 summarizes the annual doses received by this population. The annual total-body dose to the population from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with a value of about 1.6×10^{-4} man-rem received from dismantling sources. The annual total-body dose to the work force associated with dismantling was estimated based on permissible exposure limits and experience of decommissioning plants. The annual occupational dose was calculated to be 49 man-rem for dismantlement. Table 6.3.1-4 summarizes the annual total-body dose to the work force and to the regional population from decommissioning in the year 2000 and naturally occurring sources. The 70-year doses to the maximum individual and to

TABLE 6.4.1-3. Annual Doses Received by the Population (within 80 km) During the 2-yr Period of Dismantling of the Reference MOX FFP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	3.8×10^{-10}	3.8×10^{-10}	3.8×10^{-10}	3.8×10^{-10}
Inhalation	1.6×10^{-4}		1.3×10^{-2}	3.2×10^{-3}
Ingestion	3.1×10^{-8}			8.5×10^{-7}
Total	1.6×10^{-4}	3.8×10^{-10}	1.3×10^{-2}	3.2×10^{-3}

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.4.1-4. Summary of Annual Total-Body Doses Received During the 2-yr Period of Dismantling of the Reference MOX FFP in the Year 2000 and from Naturally Occurring Sources

	Dose, man-rem
MOX FFP	
Dismantling force (average annual dose)	0.3
Population (within 80 km)	<0.001
Naturally occurring sources	200,000
Population (within 80 km)	

the population within 80 km of the facility are given in Tables 6.4.1-5 and 6.4.1-6 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.4.1-7.

TABLE 6.4.1-5. 70-Year Dose to the Maximum Individual from Dismantling of the Reference MOX FFP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}
Inhalation	1.5×10^{-7}		9.3×10^{-7}	2.9×10^{-6}
Ingestion	5.0×10^{-9}			1.4×10^{-7}
Total	1.5×10^{-7}	1.5×10^{-14}	9.3×10^{-7}	3.0×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the site center with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.
a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to result in the exposed population per million man-rem.

TABLE 6.4.1-6. 70-Year Dose to the Population (within 80 km) from Dismantling of the Reference MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.8×10^{-10}	3.8×10^{-10}	3.8×10^{-10}	3.8×10^{-10}
Inhalation	3.8×10^{-3}		2.4×10^{-2}	7.5×10^{-2}
Ingestion	5.5×10^{-5}			1.5×10^{-3}
Total	3.8×10^{-3}	3.8×10^{-10}	2.4×10^{-2}	7.7×10^{-2}

TABLE 6.4.1-7. Summary of 70-Year Total-Body Doses Received from Dismantling of the Reference MOX FFP

	Dose, man-rem
MOX FFP	
Dismantling force	98
Population (within 80 km)	<0.001
Naturally occurring sources	14,000,000
Population (within 80 km)	

6.4.1.5 Ecological Effects

No adverse ecological impacts are expected from dismantling the reference MOX FFP. Chemicals used during decontamination that are potentially harmful to terrestrial plants and animals will be processed through the waste treatment facility and are not expected to be released to the biosphere.

Water used during dismantling will be withdrawn from the R River. Removal of this water is judged to be insignificant with respect to other downstream uses and no effects are expected on aquatic ecosystems.

6.4.1.6 Injuries and Fatalities

Injuries and fatalities associated with nonradiological dismantling accidents were calculated using an injury rate of 13.6 per million man-hr (construction) and a fatality rate of 0.17 per million man-hr. For 0.34 million man-hr devoted to nonradiological dismantling operations, five injuries and no fatalities will result.

6.4.1.7 Accidents

Quantities of radioactive materials contained in facilities to be decommissioned will be several orders of magnitude less than during operation of the facility. The potential for significant releases of radioactive material to the biosphere during decommissioning would be small when compared with similar accidents occurring during operation of the facility. Therefore, no accident scenarios are included for facility decommissioning operations.

Accident scenarios associated with transportation of non-high-level transuranic wastes generated by decommissioning activities are included as part of Section 7.3.2.

REFERENCES FOR SECTION 6.4.1

1. Compilation of Air Pollutant Emission Factors, 2nd ed., AP 42, Environmental Protection Agency, Research Triangle Park, NC, April 1973.

2. Air Quality Impacts Due to Construction of LWR Waste Management Facilities, URS 7043-01-01, URS Company, San Mateo, CA, June 1977.

6.4.2 Decommissioning of a MOX FFP by Entombment (Hardened Safe Storage)

Some aspects of entombing a MOX FFP may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of entombing activities.

6.4.2.1 Resource Commitments

The reference MOX FFP site consists of a 400-ha plot, with a 6-ha exclusion area that contains the MOX facility. Entombment requires that the 6-ha exclusion area of the facility site be occupied indefinitely by the entombed facility. The remaining 390 ha of the site can be released for alternative uses at the discretion of the facility owner. Activities at the site may be restricted to ensure the continued integrity of the entombment structure.

Water used during entombing is estimated to be 1.1×10^3 m^3 during chemical decontamination. Withdrawal of this amount of water from the R River, (average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses. After chemical decontamination is completed, water requirements will be limited to sanitary needs of a work force of 50 people during the remainder of the entombment process.

Materials committed for entombing the reference MOX FFP are:

Steel shipping containers	50 MT
Paper, wood, plastic	20 MT
Equipment (mostly steel)	5 MT

Energy resources committed for entombing the MOX FFP are limited to 5 MWh of electricity.

Entombment of the MOX FFP will require 100 man-yr. An additional 600 man-hr/yr will be required for an indefinite period of interim care.

6.4.2.2 Process Effluents

Routine radioactive effluents released during entombing would be limited to airborne releases. No routine releases of radioactive materials to water or ground have been identified. Estimates of routine atmospheric releases of gases and particulates are summarized in Table 6.4.2-1.

6.4.2.3 Radioactive Wastes

During the latter stages of entombment 160 m^3 of transuranic waste are generated and must be packaged and sent offsite for treatment and disposal. Less than 1 m^3/yr of radioactive waste is generated during the interim care period.

TABLE 6.4.2-1. Radionuclides Released to the Biosphere During 2-yr Period of Entombing of the Reference MOX FFP

Radionuclide	Release, Ci
^{238}Pu	1.2×10^{-7}
^{239}Pu	8.8×10^{-9}
^{241}Pu	2.2×10^{-6}
^{241}Am	7.0×10^{-8}

6.4.2.4 Radiological Effects

Doses to individuals in the vicinity of the reference MOX FFP during entombment were calculated based on the releases of radionuclides listed in Table 6.4.2-1; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). Exposure pathways to man exist only for airborne effluents released to the environment. There are no planned releases to water or ground.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.4.2-2. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 6.4.2-2. Annual Doses Received by the Maximum Individual During 2-yr Period of Entombing of the Reference MOX FFP (rem)

Pathway	Total Body	Thyroid (child)[a]	Thyroid[b]	Lung	Bone
Air submersion	1.5×10^{-16}	1.5×10^{-16}	1.5×10^{-16}	1.5×10^{-16}	1.5×10^{-16}
Inhalation	6.1×10^{-11}			4.9×10^{-9}	1.2×10^{-9}
Ingestion	2.6×10^{-14}				7.2×10^{-13}
Total	6.1×10^{-11}	1.5×10^{-16}	1.5×10^{-16}	4.9×10^{-9}	1.2×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the site center with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 6.4.2-3 summarizes the annual doses received by this population. The annual total-body population dose received from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 1.6×10^{-6} man-rem received from decommissioning sources.

TABLE 6.4.2-3. Annual Doses Received by the Population (within 80 km) During 2-yr Period of Entombing of the Reference MOX FFP (man-rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	3.8×10^{-12}	3.8×10^{-12}	3.8×10^{-12}	3.8×10^{-12}
Inhalation	1.6×10^{-6}	0	1.3×10^{-4}	3.2×10^{-5}
Ingestion	3.0×10^{-10}	0	0	8.0×10^{-9}
Total	1.6×10^{-6}	3.8×10^{-12}	1.3×10^{-4}	3.2×10^{-5}

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The annual total-body dose to the work force associated with decommissioning was estimated based on permissible exposure limits and experience of decommissioning plants. Table 6.4.2-4 summarizes the annual total-body dose to the work force and the general population from decommissioning and naturally occurring sources in the year 2000. The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.4.2-5 and 6.4.2-6 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 6.4.2-7.

TABLE 6.4.2-4. Summary of Annual Total-Body Doses Received During 2-yr Period of Entombing of the Reference MOX FFP in the Year 2000 and from Naturally Occurring Sources

	Dose, man-rem
MOX FFP	
Entombming force (average annual dose)	27
Population (within 80 km)	<0.001
Naturally occurring sources	200,000
Population (within 80 km)	

TABLE 6.4.2-5. 70-Year Doses to the Maximum Individual from Entombing of the Reference MOX FFP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	1.5×10^{-16}	1.5×10^{-16}	1.5×10^{-16}	1.5×10^{-16}
Inhalation	1.5×10^{-9}		9.3×10^{-9}	2.9×10^{-8}
Ingestion	4.7×10^{-11}			1.3×10^{-9}
Total	1.6×10^{-9}	1.5×10^{-16}	9.3×10^{-9}	3.0×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the site center with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.4.2-6. 70-Year Doses to the Population (within 80 km) from Entombing of the Reference MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.8×10^{-12}	3.8×10^{-12}	3.8×10^{-12}	3.8×10^{-12}
Inhalation	3.8×10^{-5}		2.4×10^{-4}	7.5×10^{-4}
Ingestion	5.2×10^{-7}			1.4×10^{-5}
Total	3.8×10^{-5}	3.8×10^{-12}	2.4×10^{-4}	7.6×10^{-4}

TABLE 6.4.2-7. Summary of 70-Year Total-Body Doses Received During Entombing of the Reference MOX FFP

	Dose, man-rem
MOX FFP	
Entombment force	54
Population (within 80 km)	<0.001
Naturally occurring sources	14,000,000
Population (within 80 km)	

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined (Section 6.5). In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to result in the exposed population per million man-rem.

6.4.2.5 Ecological Effects

No adverse ecological impacts are expected from entombment of the reference MOX FFP. Chemicals used during decontamination that are potentially harmful to terrestrial plants and animals will be processed through the waste treatment facility and are not expected to be released to the biosphere.

Water used during entombment, which will be withdrawn from the R River, is judged to be insignificant with respect to other downstream uses and no effects are expected on aquatic ecosystems.

6.4.2.6 Injuries and Fatalities

Injuries and fatalities associated with nonradiological entombment accidents were calculated using an injury rate of 13.6 per million man-hours (for construction) and a fatality rate of 0.17 per million man-hours. For 0.8 million man-hr devoted to entombment operations (including 10^3 years of interim care), 11 injuries and no fatalities are projected.

6.4.2.7 Accidents

Quantities of radioactive materials contained in facilities to be decommissioned will be several orders of magnitude less than those present during operation of the facility. The potential for significant releases of radioactive material to the biosphere during decommissioning would be small when compared with similar accidents occurring during operation of the facility. Therefore, no accident scenarios are included for facility decommissioning operations.

Accident scenarios associated with transportation of non-high-level transuranic wastes generated by decommissioning activities are included as a part of Section 7.3.2.

6.4.3 Comparison of Environmental Effects Between Alternatives for Decommissioning a MOX FFP

Two modes of decommissioning the reference MOX FFP have been considered: dismantlement and entombment (hardened safe storage). Dismantlement involves the removal of contaminated equipment and structures from the site within 2 to 3 years after shutdown. Entombment involves isolation of contaminated equipment and structures within existing facilities to preclude the release of any radioactive material. The 6-ha exclusion area will be maintained under interim care indefinitely. Selected aspects of decommissioning alternatives are presented in Tables 6.4.3-1 through 6.4.3-3.

In terms of resource commitments, other than land use, dismantlement requires ten times more resource materials than does entombment.* Transuranic wastes that are generated during dismantlement and require shipment to a repository will have a volume ten times greater than that generated by entombment operations. Fuel requirements for transportation of wastes to the reference repository will be 27 times greater for dismantlement than for entombment. Manpower required for decommissioning is a factor of 2 higher for entombment, if 10^3 years of interim care after entombment are included. Physical, chemical, and thermal effects will be greater when dismantlement is used. In either case these effects are easily mitigated or are insignificant.

TABLE 6.4.3-1. Resources Committed for Alternative Modes of Decommissioning the MOX FFP

Resource	Dismantlement	Entombment
Land,[a] ha	0	6
Water, m^3	100	100
Materials		
Steel shipping containers, MT	450	50
Equipment (mostly steel), MT	100	5
Energy		
Electricity, kWh	10,000	5,000
Manpower, man-yr	170	400[b]

a. Land commitment at the MOX FFP site after completion of decommissioning.
b. Includes resource commitments during 10^3 years of surveillance.

Comparison of the radiological aspects during decommissioning indicate that maximum individual and population doses for facility decommissioning are similar for both modes. The maximum

* For this comparison, entombment must exist for many thousands of years. Otherwise the very long-lived radionuclides would still require disposal in a repository and roughly the same commitments would be necessary as for prompt dismantlement.

TABLE 6.4.3-2. Radionuclides Released to the Biosphere During 2-yr Period of Decommissioning of the Reference MOX FFP

Radionuclide	Amount Released, Ci/yr	
	Dismantling	Entombing
^{238}Pu	1.2×10^{-5}	1.2×10^{-7}
^{239}Pu	8.8×10^{-7}	8.8×10^{-9}
^{240}Pu	1.8×10^{-6}	
^{241}Pu	2.2×10^{-4}	2.2×10^{-6}
^{241}Am	7.0×10^{-6}	7.0×10^{-8}

individual and population doses received from transportation of transuranic wastes will be ten times higher when dismantlement is chosen. In either case doses from decommissioning or transportation of transuranic wastes will be less than 1% of the doses received from naturally occurring sources.

Accident scenarios for both modes of decommissioning were determined to be the same and both involved transportation of transuranic wastes. Postulated minor accidents would not result in any radioactive releases to the environment. One postulated moderate accident would involve a waste container subjected to severe impact and fire with the subsequent release of 10^{-15} of the contained transuranic waste in the form of respirable particles. No severe accidents were postulated.

In summary, differences between the two decommissioning modes are due mainly to the quantities of waste shipped to distant repositories. Dismantlement commits a factor of 27 more resources and a factor of 10 more population doses (from transportation of transuranic wastes generated) than does entombment. No significant differences in terms of manpower, ecological effects, or radiation doses to the population within an 80-km radius of the facility exist between the two modes of decommissioning.

TABLE 6.4.3-3. Comparison of Radiological Aspects of Alternative Modes for Decommissioning the MOX FFP

	Dismantling	Entombing
70-year Dose to Maximum Individual, rem		
Total body	1.6×10^{-7}	1.6×10^{-9}
Thyroid	1.5×10^{-14}	1.5×10^{-16}
Lung	9.3×10^{-7}	9.3×10^{-9}
Bone	3.0×10^{-6}	3.0×10^{-8}
70-year Dose Maximum Individual from Direct Radiation from Non-High-Level Transuranic Waste Shipments		
Total body	8.8×10^{-5}	3.4×10^{-6}
(Dose from naturally occurring sources for same period, 7.0 rem)		
70-year Dose to Regional Population (2×10^{6} persons within 80 km) man-rem		
Total body	3.8×10^{-3}	3.8×10^{-5}
Thyroid	3.8×10^{-10}	3.8×10^{-12}
Lung	2.4×10^{-2}	2.4×10^{-4}
Bone	7.7×10^{-2}	7.6×10^{-4}
70-year Dose to Regional Population from Direct Radiation from Non-High-Level Transuranic Waste Shipments		
Total body	1.4	6×10^{-2}
(Dose from naturally occurring sources for same period, 1.4×10^{7} man-rem)		
2-year Dose to Decommissioning Work Force, man-rem		
Total body	9.8×10^{1}	5.4×10^{1}
70-Year Dose Commitment to Maximum Individual from Moderate Accidents, rem		
Total body	3×10^{-3}	3×10^{-3}

Notes: There is no release of ^{3}H, ^{14}C, or ^{85}Kr, therefore there is no worldwide dose. Doses from minor accidents are negligible for either decommissioning option. No severe accidents were postulated.

6.5 COMBINED EFFECTS OF WASTE MANAGEMENT FACILITIES AT THE REFERENCE MOX-FFP

6.5 COMBINED EFFECTS OF WASTE MANAGEMENT FACILITIES AT THE REFERENCE MOX FFP

The reference MOX FFP contains four waste management facilities: 1) failed equipment disassembly and packaging facility, 2) incineration of general trash and combustible waste facility, 3) cement immobilization facility, and 4) outdoor surface interim storage facility. The environmental effect of waste management at the MOX FFP is the sum of the effects of these facilities and of decommissioning the MOX FFP.

6.5.1 Environmental Effects Related to Facility Construction

Environmental effects related to construction of individual waste management facilities associated with the MOX FFP were determined to be insignificant. As facilities are aggregated, however, the potential for significant effects increases. The following information is provided to form a basis for estimating the potential environmental effects that may result from construction of waste management facilities at a MOX FFP.

6.5.1.1 Resource Commitments

Land area required for radioactive waste management facilities at the reference MOX FFP amounts to a total of 3400 m^2, of which 2400 m^2 is for on-plant storage of wastes pending disposal at a deep geologic repository. This area may be compared with the 60,000 m^2 occupied by the production facilities at the MOX FFP. An additional 10 ha will be required for construction laydown and parking areas. An area of 12 ha will be occupied by an access road and transmission line right-of-way required for the MOX FFP.

The total amount of water needed for construction of the waste management facilities at the reference MOX FFP amounts to 5.9×10^3 m^3. Water committed for construction of the MOX FFP is 4.9×10^4 m^3.

Commitments of other resources during construction of the waste management and production facilities are listed in Table 6.5.1-1.

Construction of waste management facilities adds on the order of 10% to the resources required for the MOX FFP production facilities.

6.5.1.2 Physical and Chemical Effects

Nonradioactive pollutants released to the atmosphere during construction of the MOX FFP waste management facilities result from the combustion of fuel in construction vehicles and machinery, fugitive dust from ground clearing operations, and particulates from concrete batch operations. The pollutants released are listed in Table 6.5.1-2. Also included in Table 6.5.1-2 are amounts of pollutants released to the atmosphere from construction of the production facilities of the MOX FFP.

Concentrations of carbon monoxide resulting from construction force traffic and construction equipment emissions were found to be less than ambient air quality standards. Evaluation of hydrocarbon and nitrogen oxides emissions indicated no significant effects.

TABLE 6.5.1-1. Resources Committed for Construction of the MOX FFP and its Waste Management Facilities

	Waste Management Facilities	MOX FFP Production Facilities
Construction materials		
Steel, MT	6.6×10^2	6.4×10^3
Copper, MT	6.9	5.4×10^1
Zinc, MT		9
Aluminum, MT		4
Lumber, m^3	1.8×10^2	7.1×10^2
Concrete, m^3	3.0×10^3	1.1×10^4
Energy		
Propane, m^3	4.1×10^1	3.8×10^2
Diesel fuel, m^3	4.2×10^2	4.5×10^3
Gasoline, m^3	3.2×10^2	3.0×10^3
Electricity		
Peak demand, kW	3.0×10^2	1.0×10^3
Total consumption, kWh	2.8×10^5	3.2×10^6
Labor		
Manpower, man-yr	1.9×10^2	2.0×10^3

TABLE 6.5.1-2. Pollutants Released to the Atmosphere During Construction of the Waste Management and Production Facilities at the MOX FFP, MT/yr

Pollutant	Waste Management Facilities	Production Facilities
Carbon monoxide	1.6×10^2	1.5×10^3
Hydrocarbons	7.2	7.0×10^1
Nitrogen oxides	2.9×10^1	3.1×10^2
Sulfur oxides	1.8	1.8×10^1
Particulates	4.4×10^1	4.6×10^2

6.5.1.3 Ecological Effects

Construction of combined waste management facilities at the MOX FFP will remove, for the life of the plant, about 0.3 ha from its present use for agriculture and wildlife at the reference site. Removal of this small amount of land will have no significant effect on terrestrial biota. The small effect that may result would not be distinguishable from that associated with construction of the MOX FFP itself. During construction of the MOX FFP there will be some disturbance of animals from fugitive dust, noise, and human activities. These disturbances will be confined mainly to the 400-ha MOX FFP site and the service rights-of-way. Erosion caused by runoff may deposit silt in nearby surface waters unless attention is given to control drainage by proper ditching, grading, and silt catchment. After construction is completed and vegetation is reestablished or surfacing is completed in the disturbed areas, this problem will be reduced.

Water used during construction would be less than 0.01% of the 40-year recorded minimum low flow of the R River or less than 0.001% of the average river flow. Removal of this volume of water from the R River should have an insignificant impact on the stream biota.

The maximum concentrations of particulates, sulfur dioxide, and carbon monoxide will occur within the 400-ha MOX FFP site. No measurable detrimental effects on the terrestrial ecosystem are anticipated.

6.5.2 Environmental Effects Related to Facility Operation

Factors relating to operation of the combined waste management facilities at the MOX FFP may have some effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

6.5.2.1 Resource Commitments

Resources required during planned operation of the waste management facilities at the MOX FFP are listed in Table 6.5.2-1.

TABLE 6.5.2-1. Utilities and Materials Required for Operation of the Waste Management Facilities at the MOX FFP

Resource	Average Annual Use
Electricity, MWh	1.4×10^6
Water consumed, m^3	8.4×10^2
Steel drums	1.6×10^3
Fuel	
Propane, m^3	1.0×10^4
Diesel, m^3	5.3×10^1
Acetylene, MT	5.0×10^{-2}
NaOH, MT	3.8
Cardboard boxes	4.6×10^2
Cement, MT	3.7×10^2
Lime, MT	6.3
Manpower, man-yr	8.6

This commitment of resources is not expected to have any significant effect on other industrial needs.

6.5.2.2 Process Effluents

Table 6.5.2-2 shows the amounts of radioactive materials that reach the biosphere after leaving the MOX FFP waste management facilities and passing through the reference MOX FFP atmospheric protection system. The radionuclides listed are those that will contribute at least 1% to the total dose to a given organ from any pathway to man or that are otherwise of interest.

TABLE 6.5.2-2. Estimated Annual Releases of Radionuclides the Atmosphere from Operation of the Waste Management Facilities at the MOX FFP (Minor Accidents at Low-Level TRU Storage Facility)

Radionuclide	Release, Ci
^{238}Pu	1.1×10^{-4}
^{239}Pu	7.2×10^{-6}
^{240}Pu	1.6×10^{-5}
^{241}Pu	3.5×10^{-3}
^{241}Am	2.9×10^{-3}

About 1.7×10^6 MJ of heat will be released annually from the waste management facilities via the MOX FFP cooling tower. The MOX FFP cooling tower releases about 9.4×10^7 MJ of waste heat annually. The waste management facilities release an additional 2.4×10^5 MJ via the MOX FFP stack.

Chlorine or other biocide will be used to prevent fouling in the cooling tower system. Releases or blowdown will be regulated to meet currently accepted concentrations of chlorine in the receiving waters.

There are no planned releases of radioactive material to the biosphere via liquid effluent streams.

Nonradioactive effluents released to the atmosphere during operation of MOX FFP are listed in Table 6.5.2-3.

TABLE 6.5.2-3. Nonradioactive Pollutants Released to the Atmosphere from Operation of the Waste Management Facilities at the MOX FFP

Pollutant	Release, MT/yr
Hydrogen chloride	0.008
Sulfur oxide	0.015
Nitrogen oxide	0.033
Carbon monoxide	0.017
Particulates	0.036

6.5.2.3 Physical, Chemical, and Thermal Effects

The annual release of 1.7×10^6 MJ (at a maximum rate of 1.1×10^3 MJ/hr) of heat through the MOX FFP cooling tower is not expected to have any significant thermal effects or measurable micrometeorological effects.

Atmospheric effects resulting from operation of the reference MOX FFP include air quality impacts resulting from emission of nonradioactive pollutants. Annual average and maximum ground level concentrations of pollutants released from the reference MOX FFP were computed using annual average atmospheric dispersion factors ($\overline{\chi}/Q'$) listed in the reference environment for a 20-m stack release and considering plume rise and deposition. These concentrations are listed in Table 6.5.2-4.

TABLE 6.5.2-4. Concentrations of Nonradioactive Pollutants at the MOX FFP Fenceline from Operation of Waste Management Facilities

Pollutant	Concentration, μg/m³ Maximum	Average	Standards,[a] μg/m³
Hydrogen chloride	<0.001	<0.001	7,000
Sulfur oxide	<0.001	<0.001	80
Nitrogen oxide	0.001	<0.001	100
Carbon monoxide	<0.001	<0.001	10,000
Particulates	<0.001	<0.001	75

Note: Concentrations of all listed pollutants are substantially below guides currently in use.
a. All concentrations given are Federal air quality standards with the exception of hydrogen chloride, which is a threshold limit value.

Makeup for the cooling towers will require that 8.4×10^2 m^3/yr of water be withdrawn from the R River, which has an average annual flow of 4×10^9 m^3. This amount will be less than 0.001% of the average annual river flow. About 1.3×10^2 m^3/yr of water is returned to the river as cooling tower blowdown.

6.5.2.4 Radiological Effects

Doses to individuals in the vicinity of the MOX FFP were calculated based on the radionuclides released from waste management facilities as listed in Table 6.5.2-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclides releases (Appendix B). For planned operations of the MOX FFP waste management facilities the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual dose to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 6.5.2-5. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 6.5.2-6 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem, compared with the value of about 0.003 man-rem received from process sources as given in Table 6.5.2-7.

The annual total-body dose to the work force associated with the MOX FFP waste management facilities was estimated based on permissible exposure limits and experience of operating plants. The annual dose was calculated to be 90 man-rem. Table 6.5.2-7 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 6.5.2-5. Annual Doses to Maximum Individual from Gaseous Effluents Released During Operation of the Waste Management Facilities at the MOX FFP (rem)

Pathway	Total Body	Thyroid[(a)]	Lung	Bone
Air submersion	3.7×10^{-13}	7.6×10^{-16}	7.6×10^{-16}	7.6×10^{-16}
Inhalation	3.2×10^{-7}		2.0×10^{-5}	7.2×10^{-6}
Ingestion	3.2×10^{-11}			8.0×10^{-10}
Total	3.2×10^{-7}	7.6×10^{-16}	2.0×10^{-5}	7.2×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.5.2-6. Annual Doses to Population (within 80 km) from Gaseous Effluents Released During Operation of the Waste Management Facilities at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	3.2×10^{-9}	2.0×10^{-11}	2.0×10^{-11}	2.0×10^{-11}
Inhalation	2.7×10^{-3}		1.7×10^{-1}	6.1×10^{-2}
Ingestion	2.5×10^{-7}			8.9×10^{-6}
Total	2.7×10^{-3}	2.0×10^{-11}	1.7×10^{-1}	6.1×10^{-2}

TABLE 6.5.2-7. Summary of Annual Total-Body Doses Received During Operation of the Waste Management Facilities at the MOX FFP and Naturally Occurring Sources

	Dose, man-rem
Waste management facilities	
Process work force	90
Population (within 80 km)	0.003
Naturally occurring sources	200,000
Population (within 80 km)	

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 6.5.2-8 and 6.5.2-9 respectively. Table 6.5.2-10 gives a summary of the 70-year total-body doses to the work force and the population dose from naturally occurring sources, which amounts to about 14,000,000 man-rem compared with 1.8 man-rem received from the waste management facilities.

All doses calculated include doses from routine releases and from minor accidents within each MOX FFP process facility. No releases of ^3H, ^{14}C, or ^{85}Kr are associated with MOX FFP operation; therefore, no worldwide doses will occur.

In this report, 100 to 800 health effects (cancer mortalities or serious genetic effects) are postulated to result in the exposed population per million man-rem. Based on this

TABLE 6.5.2-8. 70-Year Doses to Maximum Individual from Gaseous Effluents Released During Operation of the Waste Management Facilities at the MOX FFP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Ground Contamination	7.8×10^{-8}	7.5×10^{-8}	7.5×10^{-8}	1.1×10^{-7}
Air submersion	1.1×10^{-11}	2.3×10^{-14}	2.3×10^{-14}	2.3×10^{-14}
Inhalation	2.1×10^{-4}		1.1×10^{-3}	4.4×10^{-3}
Ingestion	7.3×10^{-10}			1.2×10^{-6}
First generation total	2.0×10^{-4}	2.3×10^{-14}	1.1×10^{-3}	4.4×10^{-3}
Second generation total	7.0×10^{-8}	6.8×10^{-8}	6.8×10^{-8}	9.7×10^{-8}
Third generation total	6.3×10^{-8}	6.1×10^{-8}	6.1×10^{-8}	8.7×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 3.6×10^{-7} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 6.5.2-9. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released During Operation of the Waste Management Facilities at the MOX FFP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Ground Contamination	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	3.9×10^{-4}
Air submersion	9.6×10^{-8}	5.9×10^{-10}	5.9×10^{-10}	5.9×10^{-10}
Inhalation	1.8		9.8	4.2
Ingestion	4.0×10^{-4}			1.4×10^{-2}
First generation total	1.8	5.9×10^{-10}	9.8	4.2
Second generation total	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	3.9×10^{-4}
Third generation total	2.6×10^{-4}	2.6×10^{-4}	2.6×10^{-4}	3.5×10^{-4}

TABLE 6.5.2-10. Summary of 70-Year Total-Body Doses Received During Operation of the Waste Management Facilities at the MOX FFP and Naturally Occurring Sources

	Dose, man-rem
Waste management facilities	
Process work force (30 year)	2,700
Population (within 80 km)	1.8
Naturally occurri sources	14,000,000
Population (within 80 km)	

occurrence rate and the 70-year regional population dose given in Table 6.5.2-9, no health effects are expected from planned operation of the waste management facilities at the MOX FFP.

6.5.2.5 Ecological Effects

The maximum heat release rate of 2900 MJ/hr to the atmosphere via the MOX FFP cooling tower is not expected to have any ecological impact. Thermal discharges to the R River via cooling tower

blowdown will not exceed a ΔT of about 17°C and will be further diluted by river flow. No perceptible impacts to the river ecosystem are foreseen from discharges of cooling water blowdown. With proper intake structure design and placement in the river, the loss of aquatic organisms through intake screen impingement and entrainment in the cooling water is not expected to have a significant impact on the river ecosystem.

Since the concentration of air pollutants are several orders of magnitude lower than the air quality standards, no impacts to the terrestrial ecosystem are expected. No toxic effects to native plant species in the reference environment are expected during the life of the MOX FFP.

6.5.3 Environmental Effects Related to Postulated Accidents

No accidents were postulated for the failed equipment disassembly and packaging facility that would lead to releases of radioactive materials to the environment.

The accident judged most severe for the incineration facility was the accident involving an explosion in the process line (Accident 4.4.4). For that accident it was assumed that an explosion in the line released 1.9% of the annual activity to the cell atmosphere for a period of 30 min. The radionuclides entered the atmosphere via the MOX FFP stack. Radionuclides released during this accident are given in Table 6.5.3-1.

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 6.5.3-2. The largest dose calculated was 2.3×10^{-5} rem to the lung, which is two orders of magnitude less than the nominal 5×10^{-3} rem/yr variation in dose received from naturally occurring sources at a given location.

A number of minor accidents were postulated for the cement and bitumen immobilization facilities that would be expected to lead to releases of radioactive material. Based on the anticipated releases of all these minor accidents, weighted by their expected frequency of occurrence, an average annual release was postulated. The estimated quantities of radionuclides released to the atmosphere were included in Tables 6.2.4-9, 6.2.4-20 and 6.5.3-1.

Annual doses were calculated for these releases for the maximum individual and the regional population. Seventy-year dose commitments for each class were also calculated. These doses were calculated using average annual atmospheric dispersion factors. In no case was the resulting dose greater than 2×10^{-12} rem for any individual dose and most often was several orders of magnitude less and did not constitute a radiological impact.

The most serious accident postulated for the MOX FFP occurred in the waste storage facility (Accident 5.3.1). In this accident three boxes containing contaminated, failed equipment are ruptured during a tornado strike while the containers are being stacked, and 0.001 of their contents is entrained in the atmosphere. The estimated amounts of radionuclides released to the environment are also given in Table 6.5.3-1.

TABLE 6.5.3-1. Radionuclides Released to the Atmosphere from Accidents in the Waste Management Facilities at the MOX FFP (Ci)

Radionuclides	(Table 6.2.3-11) Incineration Facility	(Table 6.2.4-9 and 20) Immobilization Facility	(Table 6.3.1-8) Interim Storage Facility
^{237}U	2.3×10^{-10}		
^{238}Pu	2.9×10^{-7}	9.1×10^{-13}	2.3×10^{-2}
^{239}Pu	2.0×10^{-8}	6.2×10^{-14}	1.6×10^{-3}
^{240}Pu	4.0×10^{-8}	1.2×10^{-13}	
^{241}Pu	8.8×10^{-6}	2.8×10^{-11}	7.1×10^{-1}
^{241}Am	1.5×10^{-8}	2.3×10^{-13}	1.2×10^{-3}

TABLE 6.5.3-2. 70-Year Dose Commitment to the Maximum Individual from Accidents in the Waste Management Facilities at the MOX FFP (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		Incineration (Table 6.2.3-12)			
Air submersion	1.3×10^{-13}	7.2×10^{-14}	7.2×10^{-14}	7.2×10^{-14}	7.2×10^{-14}
Inhalation		4.4×10^{-6}		2.3×10^{-5}	9.5×10^{-5}
Total	1.3×10^{-13}	4.4×10^{-6}	7.2×10^{-14}	2.3×10^{-5}	9.5×10^{-5}
		Immobilization			
		All doses $<1.0 \times 10^{-6}$ rem			
		Interim Storage (Table 6.3.1-9)			
Air submersion	3.2×10^{-14}	1.7×10^{-14}	1.7×10^{-14}	1.7×10^{-14}	1.7×10^{-14}
Inhalation		1.0×10^{-6}	0	5.4×10^{-6}	2.2×10^{-5}
Total	3.2×10^{-14}	1.0×10^{-6}	1.7×10^{-14}	5.4×10^{-6}	2.2×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location 1100 m southeast of the stack with a time integrated atmospheric dispersion coefficient of (E/Q) of 3.5×10^{-5} sec/m^3.

The 70-year dose commitment to the maximum individual from the release of radioactive materials (given in Table 6.5.3-1) is given in Table 6.5.3-2.

Decommissioning by dismantling will add less than 1% to the dose from combined waste management facilities at the MOX FFP.

6.5.3.1 Ecological Effects

No accident scenarios have been developed that would cause significant ecological impacts. However, the accidental environmental release of transported or stored process chemicals, (e.g., chlorine, acids, and caustics) could result in significant impacts to both terrestrial and aquatic ecosystems; therefore such accidents must be addressed in site-specific environmental evaluations.

6.5.4 Socioeconomic Impacts of Construction and Operation of a MOX FFP

Socioeconomic impacts associated with the construction and operation of a MOX FFP depend largely on the numbers of persons who move into the county where the facility will be located. Because of this, the size of the local population influx was forecasted, and estimates of their needs for locally provided social services were determined. Specific economic impacts attributed to this facility are not treated because they are too dependent on local site characteristics to allow for generalization.

Employment levels used to forecast socioeconomic impacts of construction were 54 persons for the construction period from 1980 to 1984 and 16 persons for the operation period beginning in 1985.

Socioeconomic impacts also depend on site characteristics (Section 3) and the assumptions used in the forecasting model as presented in Appendix C. Site characteristics that are especially important in influencing the size of the impacts forecasted include the availability of local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (population size, degree of urbanization, etc.) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible, and the areas differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts.

The socioeconomic model used in this analysis forecasts a regional population in 5-year intervals in the absence of any project activities. This population forecast serves both as a comparative baseline and as a source for a portion of the postulated future project employment. The model takes account of both primary and secondary employment effects (such as additional retail store clerks), and incorporates as separate components spouses and other dependents of members of the labor force. Regional migrants associated with the project are distributed residentially to counties throughout the commuting region. The model accounts for separation and retirement from project employment and replacement by a new labor force. It also specifies the tendency of workers and their dependents to leave the region upon job completion.

Population forecasts for the construction and operation of the reference MOX FFP are given in Table 6.5.4-1.

Forecasted in-migration is small under both expected and maximum impact conditions. As Table 6.5.4-2 shows, social service demands, which are direct multiples of forecasted in-migration, are trivial for every category of social service. Socioeconomic impacts associated with construction and operation of the reference MOX FFP are thus judged to be insignificant.

TABLE 6.5.4-1. Forecasts of Population Influx for the MOX FFP (Number of Persons)

Site	1980	1985	2000	2015
		Expected Impact		
Southeast	1 (0.0%)	10 (0.0%)	11 (0.0%)	13 (0.0%)
Midwest	2 (0.0%)	25 (0.0%)	29 (0.0%)	33 (0.0%)
Southwest	6 (0.0%)	34 (0.1%)	40 (0.1%)	45 (0.1%)
		Maximum Impact		
Southeast	7 (0.0%)	27 (0.1%)	31 (0.1%)	35 (0.1%)
Midwest	8 (0.0%)	48 (0.1%)	57 (0.1%)	64 (0.1%)
Southwest	69 (0.2%)	52 (0.1%)	60 (0.1%)	68 (0.1%)

Note: Numbers in parentheses denote percentage of the expected population influx based on the existing regional population.

TABLE 6.5.4-2. Selected Social Service Demands Associated with Migration into Site County Resulting from Construction and Operation of the MOX FFP

	Year 2000					
	Expected			Maximum		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	0	0	0	0	0	0
Nurses	0	0	0	0	0	0
Dentists	0	0	0	0	0	0
Hospital beds	0	0	0	0	0	0
Nursing care beds	0	0	0	0	0	0
Education						
Teachers (K-12)	0	0	1	0	1	1
Classroom space, m^2 (9-12)	20	50	70	60	100	100
Sanitation						
Water treatment, m^3/day	7	17	23	18	32	34
Liquid waste, m^3/day	4	11	15	12	22	23
Fire and police						
Firemen	0	0	0	0	0	0
Policemen	0	0	0	0	0	0
Government						
Administrative staff	0	0	0	0	0	0
Other social impacts						
Crimes (7 crime index)	1	1	2	2	2	4

6.5.5 Summary of Adverse Effects Associated with Waste Management Facilities at the MOX FFP

Adverse environmental effects associated with construction, operation, and decommissioning of radioactive waste management facilities at the MOX FFP appear to be few in number and nearly trivial in consequences. Over the 30-year operating life of the waste management facilities and decommissioning of the production facilities (transportation of wastes is treated in Section 7 and final isolation of wastes in Section 9), the following human and material resource commitments might be termed adverse:

- one construction fatality
- 2700 man-rem of occupational dose
- 3×10^5 m^3 propane consumed
- 1600 m^3 of diesel fuel consumed
- 2×10^6 kWh of electricity consumed

Over the life of the plant (including construction) the waste management facilities would release pollutants in the amounts of 330 MT of nitrogen oxides and 22 MT of sulfur oxides. For comparison, one 1000-MWe coal-fired plant releases about 1,700,000 MT of nitrogen oxides over the same period.

Although dose to the population is often included as an adverse impact, the calculated dose of 1.8 man-rem over 70 years is insignificant when compared with the normal dose of 14,000,000 man-rem to the same population from naturally occurring sources during the same period.

7.0 ENVIRONMENTAL EFFECTS RELATED TO TRANSPORTING RADIOACTIVE WASTES ASSOCIATED WITH LIGHT WATER REACTOR FUEL REPROCESSING AND FABRICATION

7.0 ENVIRONMENTAL EFFECTS RELATED TO TRANSPORTING RADIOACTIVE WASTES ASSOCIATED WITH LIGHT WATER REACTOR FUEL REPROCESSING AND FABRICATION

In the course of reprocessing light-water reactor (LWR) fuels, solidified high-level waste, fuel residues, and transuranic wastes will require shipment from a fuel reprocessing plant (FRP) and transuranic wastes will require shipment from a mixed-oxide fuel fabrication plant (MOX FFP) to a Federal geologic repository or, if a repository is not available, to a Federal retrievable waste storage facility. In the case of uranium-only recycle with plutonium stored as plutonium oxide (PuO_2), shipment of PuO_2 from the FRP to a PuO_2 storage facility (Federal retrievable waste storage facility) will be required. Shipment of these wastes will increase the potential for accidental releases of radioactive materials. The consequences of such accidental releases are expected to differ depending on the mode of shipment and the form and age of the wastes to be shipped.

This section examines the two principal modes of transporting fuel reprocessing wastes (namely, rail and truck) for environmental effects resulting from routine shipment and postulated accidents.

Safety during transport of radioactive material depends primarily on packaging. The packaging must meet standards established by the Department of Transportation and the Nuclear Regulatory Commission. The standards for packages containing significant amounts of radioactive materials require that the packaging prevent loss or dispersal of the radioactive contents, retain shielding efficiency, ensure nuclear criticality safety, and provide adequate heat dissipation under normal conditions or transport and under specified (hypothetical) accident damage test conditions.(1) Package contents must also be limited to meet standards for external radiation levels, temperature, pressure, and containment.

Shipment of radioactive wastes must meet Department of Transportation limitations on radiation levels outside the packaging and transport vehicle.(2) These wastes are normally shipped in exclusive-use trucks and railcars. Thus special provisions of the Department of Transportation regulations apply which limit radiation levels outside the transport vehicle to 1.0×10^{-2} rem/hr at a distance of 1.8 m from the edge of the vehicle.(2) For simplicity, all shipments are assumed to produce radiation levels at this upper limit, even though such levels are unlikely, especially in shipment of low-level wastes. Department of Transportation regulations limit radiation levels in the truck cab to 2×10^{-3} rem/hr. For this analysis the radiation level in the cab of the truck carrying high-level wastes and transuranics is assumed to be 2×10^{-3} rem/hr. For low-level wastes, most drums will contain such small quantities of radioactive material that the radiation level in the truck cab will in practice not exceed 2×10^{-4} rem/hr.(3)

Accidents can be expected to occur during shipment by rail or truck whether or not radioactive material is involved. In the analyses that follow, the number of fatalities per million vehicle (truck or railcar) kilometers was taken to be 0.039 in the case of rail transport and 0.045 in the case of truck transport. The number of serious injuries per million vehicle kilometers was taken to be 0.36 in the case of rail transport and 0.44 in the case of truck transport.(4) Accident, injury, and fatality rates for transportation vary by factors of 2 to 10, depending on assumptions.(3-6) Those used in this report are believed to be representative. In the analyses to follow, the total round-trip mileage is used because the empty shipping casks must be returned.

7.1 TRANSPORT OF SOLIDIFIED HIGH-LEVEL WASTE

7.1 TRANSPORT OF SOLIDIFIED HIGH-LEVEL WASTE

Solidified high-level waste (SHLW) is assumed to be contained in disposable stainless steel canisters with welded closures. For vitrified waste the canisters are 0.3 m inside diameter by 3.0 m long and contain about 180 ℓ of glass from the processing of about 3 MTHM. For calcined waste the canisters are 0.2 m inside diameter by 3.05 m long and contain 70 ℓ of calcine from the processing of about 3 MTHM. From nine to 36 high-level waste canisters depending on canister size can be transported in the conceptual rail cask shown in Figure 7.1.1-1.

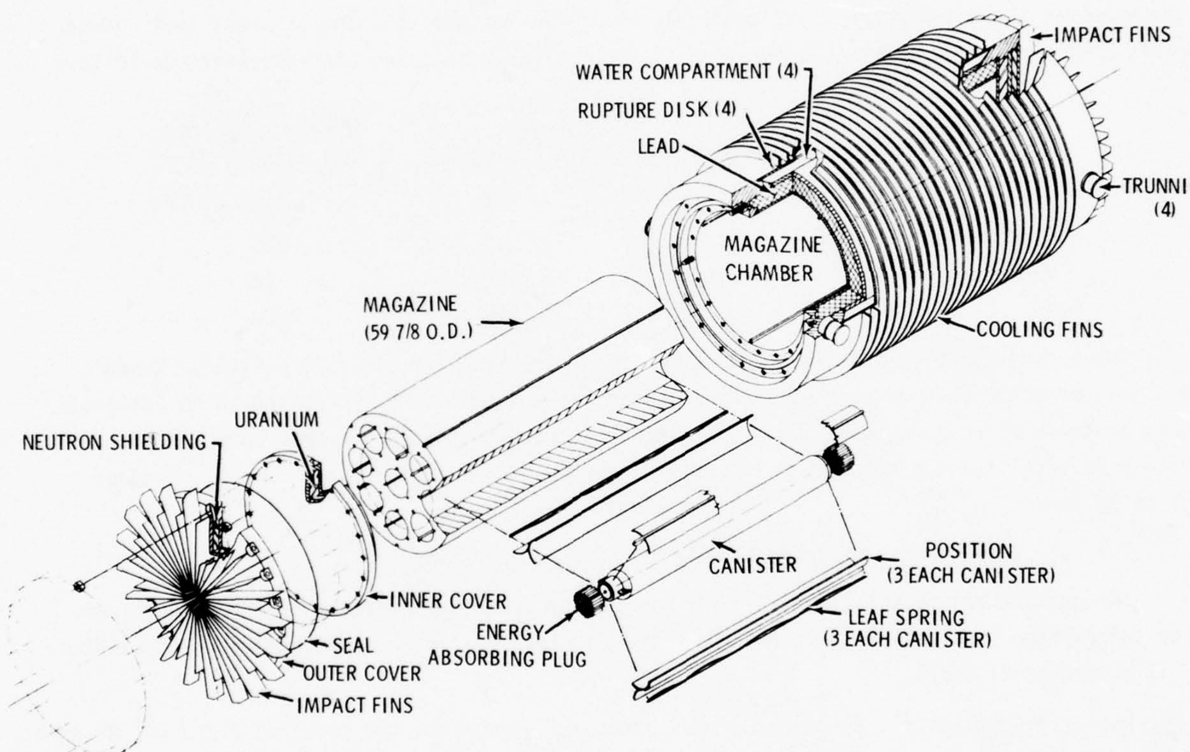

FIGURE 7.1.1-1. Conceptual Cask for Rail Shipment of Solidified High-Level Waste

The rail cask is a lead-filled double-walled stainless steel cylinder 4 m long and 2.1 m in diameter and weighs about 100 MT. In addition to the gamma shielding provided by the lead and steel structural material, neutron shielding is furnished by a water jacket that surrounds the cask body. Impact protection is provided by circumferential fins that surround the cask body and by radial fins on the ends of the cask. The cask is designed to dissipate up to 50 kJ/s (50 kW) of internally generated heat. An exclusive-use six-axle railcar is used to transport the cask. The railcar and mounting equipment weigh about 50 MT, which brings the total weight of the transport system to about 150 MT (330,000 lb).

High-level liquid waste may be solidified either as a calcine or as a glass. In routine transport, the doses to individuals in the environs are not expected to differ significantly. In the case of accidents, the two forms are likely to behave differently and the similarity in dose would no longer exist.

7.1.1 Environmental Effects Related to Rail Transport of Solidified High-Level Radioactive Waste (DOE/ET-0028 Sec. 6.3.1)

High-level waste (HLW) is not currently being commercially solidified. Casks designed specifically for shipment of SHLW have not been built. High-level waste shipping containers are expected to resemble the casks currently available for the shipment of spent fuel. Materials committed for the fabrication of the conceptual SHLW shipping containers are as follows:

	One Cask, MT	Total Required in Year 2000 (14 casks), MT	Total Required in Peak Year 2015 (29 casks), MT
Stainless steel (SS)	25	350	720
Chromium (in SS)	4.5	63	130
Nickel (in SS)	2.0	28	58
Lead	75	1000	2200

These quantities do not include allowances for the required six-axle railcars, support systems, or other equipment. Resources required for a single cask are judged to be insignificant in terms of resource use. The total resource requirements in the year 2000 are not likely to significantly affect U.S. industry needs when distributed over a period of about 15 to 30 years.

7.1.1.1 Environmental Effects Related to Routine Operation

The routine shipment of SHLW is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impact of routine rail shipments of SHLW.

Resource Commitments. Fuel requirements for rail transport are based on 7.7×10^4 MT-km/m^3 of diesel fuel.[7] For the 150-MT SHLW shipping cask and vehicle, the fuel required is obtained from an assumed shipping distance of 4800 km (round trip) between the FRP and the waste repository multiplied by the number of shipments and divided by 510 km/m^3 of diesel fuel. Fuel requirements are as follows:

	Number of Shipments	Amount of Diesel Fuel
Year 2000	200	1,900 m^3/yr
Peak Years (2015-2025)	310	2,900 m^3/yr
Through Year 2050	14,800	139,000 m^3

Transport Effluents. The heat generated by the SHLW in each shipment will be about 40 kJ/s (40 kW). Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with rail transport. Table 7.1.1-1 gives estimated average locomotive emissions.* No effluents will be released to ground or water.

* Emissions are calculated based on weight of the cask and railcar and are essentially independent of the number of cars in the train.

TABLE 7.1.1-1. Nonradioactive Pollutants Released to Atmosphere During Rail Shipment of Solidified High-Level Waste

Pollutant	Release Rate[a] MT/million km	Total Releases for All Shipments,[b] MT		
		Year 2000	Peak Year (2015)	Through 2050
Particulates	7.4	7.1	11	530
Sulfur oxides	15	14	22	1100
Carbon monoxide	35	34	52	2500
Hydrocarbons	24	23	36	1700
Nitrogen oxides	93	89	140	6600
Aldehydes	1.4	1.3	2.1	99
Organic acids	1.8	1.7	2.7	130

a. At 4800 km round trip for cask car. Total mileage for year 2000, 0.85 million km; peak year (2015), 1.7 million km; through year 2050, 67 million km.
b. Source: Computations were based on 1) emission factors in Compilation of Air Pollutant Emission Factors, 2nd ed., AP 42, Environmental Protection Agency, Research Triangle Park, NC, April 1973, and 2) energy efficiency factors for intercity freight transport in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

Physical, Chemical, and Thermal Effects. Heat rejected during rail transport of SHLW is less than three orders of magnitude of the stationary facility heat loads considered to have only minor microclimatic effects; as a consequence, no significant atmospheric effects are postulated for rail transport of SHLW. Both the heat loads and combustion product releases amount to a very small increment over total present releases associated with rail transport.

Radiological Effects. Under normal operating circumstances, no radioactive materials will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from a passing rail shipment of SHLW.

Dose is generally calculated for radiation workers (occupational exposure) and for members of the general population based on radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation doses to railroad employees were calculated assuming that the employee spends up to 10 min in the vicinity of the waste shipment for an average exposure of 1×10^{-3} rem. It was assumed that the employee is involved in about 20 shipments per year and that he is employed at the same job for 30 years. Thus, the railroad employee receives about 0.02 km annually and accumulates 0.6 rem during his career. Assuming one rail employee is exposed to the waste each 200 km of a shipment, the work force dose through the year 2050 would amount to 180 manrem.

Radiation doses received by members of the general population from direct radiation of a passing rail shipment of SHLW were calculated based on the speed of the train, distance of the shipment, and the population density along the railroad right-of-way. The calculation

of direct radiation dose to the maximum individual was based on location of the individual's residence 30 m from the center of the railroad track. The doses received by the general population were calculated using an assumed population density of 40 persons/km^2.

In the year 2000 the reference scheme has four FRPs in operation sending SHLW to one repository. In the peak year, five FRPs are sending SHLW to two repositories (one FRP will have spent its 30-year life). None of the facilities are assumed to be colocated. As a consequence, defining a realistic "maximum individual" for routine transportation is difficult. If the assumption is made that all SHLW shipments pass the same individual, his dose from direct radiation in the year 2000 would be 1.2×10^{-4} rem; in the peak year 2015 it would be 2.5×10^{-4} rem; and for the 70-year period ending 2050 it would be about 1×10^{-2} rem.

Based on a dose per shipment kilometer of 3.7 man-rem per million kilometers, the dose to the population along the transport route would amount to about 1.8 man-rem in the year 2000, about 2.8 man-rem at the peak year 2015, and about 130 man-rem over the 70-year period ending in 2050. If only one route (2400 km one way) is assumed, the population dose from naturally occurring sources (at a nominal 4 man-rem/yr-km) over the same 70-year period would be about 670,000 man-rem.

Ecological Effects. Some particulates and gases will be released to the atmosphere from combustion of fossil fuels during normal locomotive operation; however, these releases are not expected to be of ecological significance.

7.1.1.2 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with rail transport of SHLW were identified that could be expected to lead to releases of radioactive materials. Scenarios for these accidents are provided in DOE/ET-0028.[8] The accidents are listed below.

Accident Number	Description
6.3.1	Train derailment involves HLW cask
6.3.2	Train derailment and fire of 30 min (or less) in HLW cask
6.3.3	Unusual transport conditions erode cask surface

No release of radioactive material was postulated for Accidents 6.3.1 and 6.3.2. Radioactive material released in Accident 6.3.3 is presented in Table 7.1.1-2. This accident is postulated to occur once per year. Doses resulting from these releases are given in Tables 7.1.1-3 and 7.1.1-4.

Accidents postulated to release radioactive material in amounts larger than those released by minor accidents are classified as moderate and severe accidents and are listed below.

Accident Number	Description
	Moderate
6.3.4	Loss of neutron shielding in a SHLW cask
	Severe
6.3.5	HLW cask is subjected to severe impact and fire

TABLE 7.1.1-2. Radionuclides Released to the Atmosphere from Minor Accidents During Rail Transport of Solidified High-Level Waste

Radionuclide	Release, Ci		
	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{90}Sr	7.1×10^{-8}	7.1×10^{-8}	6.6×10^{-8}
^{90}Y	7.1×10^{-8}	7.1×10^{-8}	
^{95}Zr			3.7×10^{-9}
^{95}Nb	8.3×10^{-9}	8.3×10^{-9}	
^{106}Ru	1.8×10^{-7}	1.8×10^{-7}	2.1×10^{-7}
^{125m}Te	2.4×10^{-9}	2.4×10^{-9}	2.6×10^{-9}
^{127m}Te	4.6×10^{-10}	4.6×10^{-10}	4.7×10^{-10}
^{134}Cs	1.3×10^{-7}	1.3×10^{-7}	1.3×10^{-7}
^{137}Cs	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}
^{144}Ce	2.7×10^{-7}	2.7×10^{-7}	2.6×10^{-7}
^{154}Eu	6.0×10^{-9}	6.0×10^{-9}	
^{238}Pu	3.4×10^{-9}		
^{239}Pu	3.2×10^{-10}	1.6×10^{-12}	2.0×10^{-12}
^{240}Pu	5.0×10^{-10}		
^{241}Pu	1.1×10^{-7}		
^{241}Am		4.0×10^{-10}	7.7×10^{-10}
^{242}Cm	3.8×10^{-9}	3.8×10^{-9}	7.1×10^{-8}
^{244}Cm	1.3×10^{-9}	1.3×10^{-9}	7.8×10^{-9}

TABLE 7.1.1-3. Annual Dose to the Maximum Individual from Minor Accident Releases During Rail Transport of Solidified High-Level Waste

Organ	Dose, rem		
	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
Total body	4.8×10^{-7}	3.4×10^{-7}	5.4×10^{-7}
Thyroid	1.8×10^{-8}	1.8×10^{-8}	1.9×10^{-8}
Lung	3.0×10^{-5}	2.0×10^{-5}	4.6×10^{-5}
Bone	6.0×10^{-6}	2.6×10^{-6}	5.5×10^{-6}
Skin	7.0×10^{-9}	7.0×10^{-9}	7.1×10^{-9}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

TABLE 7.1.1-4. 70-Year Dose Commitment to Maximum Individual from Minor Accident Releases During Rail Transport of Solidified High-Level Waste

Organ	Dose, rem: U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
Total body	7.8×10^{-6}	3.3×10^{-6}	5.8×10^{-6}
Thyroid	1.8×10^{-8}	1.8×10^{-8}	1.9×10^{-8}
Lung	5.5×10^{-5}	3.2×10^{-5}	7.9×10^{-5}
Bone	1.2×10^{-4}	2.4×10^{-5}	6.8×10^{-5}
Skin	7.0×10^{-9}	7.0×10^{-9}	7.1×10^{-9}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

For Moderate Accident 6.3.4 (loss of neutron shielding in a SHLW cask) it is assumed that 10-year-old wastes from 27.4 MTHM will produce neutron streaming for 5 hr. No other materials are released and only recovery workers in close proximity are expected to receive any dose. The postulated frequency is 0.003 per year.

Severe Accident 6.3.5 (HLW cask is subjected to severe impact and fire) results in a ground-level fractional release of 5×10^{-8} of 10-year-old vitrified waste from processing 27.4 MTHM. The release lasts for 15 min; the amount of radioactive material released is given in Table 7.1.1-5. The release fraction is 5×10^{-6} for calcined waste. The postulated frequency of this accident is 3×10^{-6} per year.

Doses to the maximum individual immediately following the accident and the 70-year dose commitment are given in Table 7.1.1-6. Doses are presented for the case where SHLW is in glass form; doses are 100 times higher when SHLW is in calcine form.

Although about seven times larger than the permissible annual occupational exposure, a 1-year total-body dose of 37 rem from the calcined HLW accident is not expected to result in immediate danger to the health of the exposed individual. Long-term effects might be expected, however, to include serious radiation-induced illness. A dose to the lung of 2600 rem over a short period may result in serious illness and substantial life shortening. A similar accident with vitrified HLW was calculated to result in a dose of 26 rem to the lung, which would not be expected to have immediate serious effects.

Accidents Not Involving Radioactive Material. Shipment of SHLW will involve on the order of 0.96 million km in the year 2000, about 1.5 million km in the peak years of shipping SHLW, and about 71 million km over the 70-year period ending in 2050. At a fatal accident rate of 0.039 fatalities per million kilometers about three fatalities would be expected over the 70-year period. At an injury rate of about 0.36 injuries per million kilometers, about 26 injuries would be expected over the 70-year period.*

* These fatalities and disabling injuries may occur either to the transportation worker or the public.

TABLE 7.1.1-5. Radionuclides Released to the Atmosphere from a Solidified High-Level Waste Cask Subjected to Severe Impact and Fire (Ci)

	Glass Form			Calcine Form		
Radionuclide	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{90}Sr	7.1×10^{-2}	7.1×10^{-2}	6.7×10^{-2}	7.1	7.1	6.7
^{90}Y	7.1×10^{-2}	7.1×10^{-2}	6.7×10^{-2}	7.1	7.1	6.7
^{125m}Te	3.0×10^{-4}	3.0×10^{-4}	3.3×10^{-4}	3.0×10^{-2}	3.0×10^{-2}	3.3×10^{-2}
^{134}Cs	7.7×10^{-3}	7.7×10^{-3}	7.7×10^{-3}	7.7×10^{-1}	7.7×10^{-1}	7.7×10^{-1}
^{137}Cs	1.0×10^{-1}	1.0×10^{-1}	1.0×10^{-1}	1.0×10^{1}	1.0×10^{1}	1.0×10^{1}
^{238}Pu	4.0×10^{-3}			4.0×10^{-1}		
^{239}Pu	4.0×10^{-4}	2.0×10^{-6}	2.5×10^{-6}	4.0×10^{-2}	2.0×10^{-4}	2.5×10^{-4}
^{241}Pu	9.5×10^{-2}			9.5		
^{241}Am	3.8×10^{-3}	2.1×10^{-3}	3.7×10^{-3}	3.8×10^{-1}	2.1×10^{-1}	3.7×10^{-1}
^{244}Cm	1.3×10^{-3}	1.2×10^{-3}	6.9×10^{-3}	1.2×10^{-1}	1.2×10^{-1}	6.9×10^{-1}

TABLE 7.1.1-6. One-Year Doses and 70-Year Dose Commitments to Maximum Individual Resulting from a Severe Cask Accident During Rail Transport of Solidified High-Level Waste (glass form)

	Dose, rem					
	U Recycle, Pu in SHLW		U Recycle, PuO_2 Stored		U and Pu Recycle	
Group	1-Year	70-Year	1-Year	70-Year	1-Year	70-Year
Total body	3.7×10^{-1}	1.0×10^{1}	2.0×10^{-1}	4.2	3.2×10^{-1}	7.4
Bone	5.0	1.6×10^{2}	1.3	3.8×10^{1}	3.1	8.8×10^{1}
Lung	2.4×10^{1}	5.9×10^{1}	9.2	2.2×10^{1}	2.6×10^{1}	6.2×10^{1}
Thyroid	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
Skin	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.2×10^{-3}	1.2×10^{-3}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

Ecological Effects. No accidents or unusual events have been identified that would result in significant effects to terrestrial or aquatic systems.

REFERENCES FOR SECTION 7.1.1

1. Title 10, Code of Federal Regulations, Part 71, Appendix B.
2. Title 10, Code of Federal Regulations, Part 173.
3. Environmental Survey of Transportation of Radioactive Materials to and From Nuclear Power Plants, WASH-1238, U.S. Atomic Energy Commission, Washington, DC, December 1972.

4. Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Energy Research and Development Administration, Washington, DC, June 1976.

5. Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, NUREG-00.6, Nuclear Regulatory Commission, Washington, DC, October 1976.

6. R. K. Clarke, J. T. Foley, W. F. Hartman, and D. W. Larson, Severities of Transportation Accidents, SLA-74-0001, Sandia Laboratories, Albuquerque, NM, July 1976.

7. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

8. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

7.1.2 Truck Transport of Solidified High-Level Waste

Because irradiated spent fuel is currently transported by truck, a reasonable conclusion would be that trucks could also be used to transport comparable weights of solidified high-level waste (SHLW). With the exception of dollar costs and time required for shipment, however, there seems to be no advantage and several disadvantages to shipping large casks of SHLW by truck.

If the casks and payload for transport of SHLW by truck are approximately the same as those for spent fuel, a truck could be expected to carry about one-tenth the weight that a railcar could carry. As a consequence, ten trucks would be needed to ship the same weight carried by one railcar. Because of this extra distance, several important aspects arise that are unfavorable to truck transport.

The number of traffic fatalities for trains is about 0.039 per million kilometers and about 0.045 per million kilometers for trucks. However, for every million kilometers traveled by train, the truck must travel 10 million km, thus increasing fatalities by 12 times for the same load moved. The dose to the transport worker has been estimated to be 1×10^{-3} rem per shipment by rail and about 1×10^{-1} rem per shipment by truck. With ten times more truck than rail shipments, truck operators would receive doses about 1000 times greater than those received by trainmen. Population dose for the same route is governed by the speed of transport and the number of shipments. In the reference case, an approximately 1200-km/day truck shipment is 3.8 times faster than a 320-km/day train shipment; however, truck transport requires ten times more shipments than rail, thus resulting in the population dose from direct radiation of 2.7 times that associated with rail transport. In terms of fuel, rail transport obtains about 7.7×10^4 MT-km/m^3 of diesel fuel and truck transport obtains about 2.2×10^4 MT-km/m^3 of diesel fuel. At ten times the distance to be traveled, the truck will need approximately 3 times more fuel than the railcar and will produce about 3 times more atmospheric pollutants.

This analysis clearly favors rail shipment for SHLW. However, where payloads are similar, the advantages of rail transport may not be so apparent.

7.2 TRANSPORT OF FUEL RESIDUES

7.2 TRANSPORT OF FUEL RESIDUES

Fuel residues generated to date in commercial reprocessing operations have been isolated by onsite burial. Casks designed specifically for commercial shipment of fuel residues have not been built. It is assumed that systems for both rail and truck transport of these wastes can be designed to meet all applicable Federal regulations for transport of radioactive materials.

Fuel residue casks are expected to resemble casks currently available for shipment of spent fuel but will be simpler in design because heat removal requirements will be reduced and neutron shielding will not be required. The dimensions of the conceptual fuel residue canister are dictated by postulated requirements at the Federal repository. The canister is assumed to have a diameter of 76 cm (30 in.) and a length of 3.05 m (10 ft). It would be made of stainless steel with welded closures.

Because of greater payload capacity, a rail cask is postulated in this study for shipment of fuel residues from fuel reprocessing plants to interim storage or permanent isolation facilities. The conceptual cask is assumed to be a lead-filled double-walled stainless steel cylinder capable of transporting three waste canisters. The cask is 3.9 m (152 in.) long and 2.2 m (88 in.) in diameter and weighs about 65 MT (143,000 lb). Decay heat loads are low enough that cooling fins would probably not be required. Impact protection for the cask would be provided by steel-clad balsa impact limiters.

7.2.1 *Environmental Effects Related to Rail Transport of Fuel Residues* (DOE/ET-0028 Sec. 6.4.1)

Although residues (cladding wastes) are not currently being shipped, the transport of these wastes may have some effect on the environment. The information that follows is provided to form a basis for evaluating the environmental impact of transporting fuel residues by rail.

7.2.1.1 Resource Commitments Associated with Fabrication of Equipment

The conceptual rail transport container is a top-loading cylindrical cask with stainless steel liner and outer structural walls and a lead gamma shield that will hold three canisters. The materials committed to the fabrication of fuel residue rail casks with no pretreatment are

	One Cask, MT	Total Required in Year 2000 (45 Casks), MT	Total Required in Peak Year 2010 (62 Casks), MT
Stainless steel (SS)	16	790	990
Chromium (in SS)	2.9	130	180
Nickel (in SS)	1.3	60	80
Lead	49	2200	3000

These quantities do not include allowances for the special six-axle railcar, support systems, or other equipment. Resources for a single cask are judged to be insignificant in terms of resource use. The total resources required in the year 2000 are not likely to significantly affect U.S. industry needs when distributed over a period of about 15 to 25 years.

7.2.1.2 Environmental Effects Related to Routine Operation

The routine shipment of fuel residues is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impacts of shipping fuel residues by rail.

Resource Commitments. Fuel requirements for rail transport are based on 7.7×10^4 MT-km/m^3 of diesel fuel.[1] For the 100 MT shipping cask and vehicle, the fuel required is calculated based on an assumed shipping distance of 4800 km round trip between the FRP and the waste repository, multiplied by the number of shipments and divided by 770 km/m^3 of diesel fuel. The number of shipments required for each fuel residue treatment option are shown in Table 7.2.1-1. Table 7.2.1-2 gives the commitments of diesel fuel necessary for transporting fuel residues by rail.

TABLE 7.2.1-1. Shipments of Fuel Residues by Rail from Fuel Reprocessing Plants to Repositories

	Packaging Without Treatment	Mechanical Compaction	Compaction by Melting
Year 2000	597	350	237
Peak years, 2010 to 2020	673	406	268
Total through year 2050	29,900	17,500	11,900

TABLE 7.2.1-2. Diesel Fuel Needed for Transporting Fuel Residues by Rail

	Packaging Without Treatment	Mechanical Compaction	Compaction by Melting
Year 2000, m^3/yr	3.7×10^3	2.2×10^3	1.5×10^3
Peak years, 2010 to 2020, m^3/yr	4.2×10^3	2.5×10^3	1.7×10^3
Total through year 2050, m^3	1.9×10^5	1.1×10^5	7.4×10^4

Transport Effluents. Each shipment of fuel residues will generate about 0.8 kJ/s (0.8 kW) of heat. Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with rail transport. Table 7.2.1-3 contains estimated average locomotive emissions.* No effluents will be released to ground or water.

Physical, Chemical, and Thermal Effects. Heat rejected during rail shipment of fuel residues is five orders of magnitude less than the stationary facility heat loads considered to have microclimatic effects; as a consequence, no significant atmospheric effects are postulated. Both the heat loads and combustion product releases amount to a small increment over total present releases associated with rail transport.

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* Emissions given are the increases in locomotive emissions due to the addition of one car.

TABLE 7.2.1-3. Average Locomotive Emissions Attributable to Rail Transport of Fuel Residues

Pollutant	Release Rate,[a] MT/million km	Total Releases of All Shipments Based on Packaging without Compaction Option, MT[b,c] Year 2000	Peak Year	Through Year 2050
Particulates	7.4	21	24	1,100
Sulfur oxides	15	43	48	2,200
Carbon monoxide	35	100	110	5,000
Hydrocarbons	24	69	78	3,400
Nitrogen oxides	93	270	300	13,000
Aldehydes	1.4	4.0	4.5	200
Organic acids	1.8	5.2	5.8	260

a. Computations were based on 1) emission factors in Compilation of Air Pollutant Emission Factors, 2nd ed., AP 42, Environmental Protection Agency, Research Triangle Park, NC, April 1973, and 2) energy efficiency factors for intercity freight transport in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.
b. For a 4800-km round trip per cask car.
c. Mechanical compaction would result in about 60% of the emissions shown; compaction by melting would result in about 40% of the emissions.

Radiological Effects. Under normal operating circumstances, no radioactive materials will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from a passing rail shipment of fuel residues.

Dose is ordinarily calculated for radiation workers (occupational exposure) and for members of the general population based on radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation doses to railroad employees were calculated assuming that the employee spends up to 10 min in the vicinity of the waste shipment for an average exposure of 1×10^{-3} rem. It was assumed that the employee is involved in about 20 shipments per year and that he is employed at the same job for 30 years. Thus, the railroad employee receives about 0.02 rem annually and accumulates 0.6 rem during his career. Assuming one railroad employee is exposed to the waste each 200 km of a shipment, the work-force dose associated with fuel residue transport would vary from 140 man-rem for compaction by melting to 360 man-rem for no compaction.

Doses received by members of the general population from direct radiation of a passing rail shipment of fuel residues were calculated based on the speed of the train, number and distance of the shipments, and the population density along the railroad right-of-way. The calculation of direct radiation dose to the maximum individual was based on location of the individual's residence 30 m from the centerline of the railroad track. The doses received by the general population were calculated using an assumed population density of 40 persons/km^2.

The annual direct radiation doses to the maximum individual and general population are given in Table 7.2.1-4 along with the annual radiation dose to the transportation work force

for transport of fuel residues after volume reduction by compaction or melting or as packaged without compaction.

TABLE 7.2.1-4. Total-Body Doses Received from Direct Radiation of Fuel Residues Being Transported by Rail

Group	Waste Treatment: Packaging Without Compaction	Mechanical Compaction	Compaction by Melting
	Year 2000		
Maximum individual, rem/yr[a]	3.6×10^{-4}	2.1×10^{-4}	1.4×10^{-4}
Population, man-rem/yr[b]	5.4	3.2	2.1
Work force, man-rem/yr[c]	7.2	4.2	2.8
	Peak Years, 2010 to 2020		
Maximum individual, rem/yr[a]	4.0×10^{-4}	2.4×10^{-4}	1.6×10^{-4}
Population, man-rem/yr[b]	6.1	3.7	2.4
Work force, man-rem/y[c]	8.1	4.9	3.2
	Through Year 2050		
Maximum individual, rem[a]	1.8×10^{-2}	1.1×10^{-2}	7.1×10^{-3}
Population, man-rem[b]	2.7×10^{2}	1.6×10^{2}	1.1×10^{2}
Work force, man-rem[c]	3.6	2.1	1.4

a. The assumption is made that all shipments follow the same route, thus the maximum individual is exposed to each shipment.
b. Dose to the population is calculated on the basis of 3.7 man-rem per million kilometers. The annual dose to the population from naturally occurring sources along the transport route is 9.6×10^3 man-rem.
c. One brakeman is exposed to the waste for each 200 km of a shipment.

If the assumption is made that all fuel residues are shipped via the same 2400-km route, the dose to the population along the route from naturally occurring sources would amount to 9600 man-rem/yr or 670,000 man-rem over the 70-year period. Routine transport of fuel residues regardless of compaction option is not expected to result in doses of any consequence.

Ecological Effects. Some particulates and gases will be released to the atmosphere from combustion of fossil fuels during normal locomotive operation; however, these releases are not expected to be of ecological significance.

7.2.1.3 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with rail transport of fuel residues have been identified that could lead to releases of radioactive materials. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
6.4.1	Train derailment involves fuel residue cask
6.4.2	Train derailment and fire of 30 min (or less) involves fuel residues
6.4.3	Unusual transport conditions erode cask surface

No release of radioactive material was postulated for Accidents 6.4.1 and 6.4.2. Radioactive material released in Accident 6.4.3 is presented in Table 7.2.1-5. This accident is postulated to occur twice a year. One-year doses and 70-year dose commitments to the maximum individual, defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3, are presented in Table 7.2.1-6.

TABLE 7.2.1-5. Radionuclides Released to the Atmosphere from Minor Accidents During Rail Shipment of Fuel Residues

Radionuclide	Release, Ci: U Recycle, Pu in SHLW or PuO_2 Stored	Release, Ci: U and Pu Recycle
^{3}H	1.9×10^{-9}	1.9×10^{-9}
^{85}Kr	4.1×10^{-8}	3.2×10^{-8}
^{90}Sr	2.9×10^{-7}	2.7×10^{-7}
^{90}Y	2.9×10^{-7}	2.7×10^{-7}
^{91}Y	4.1×10^{-7}	4.0×10^{-7}
^{95}Zr	7.3×10^{-7}	7.3×10^{-7}
^{95}Nb	1.4×10^{-6}	1.4×10^{-6}
^{106}Ru	1.5×10^{-6}	1.6×10^{-6}
^{125m}Te	1.2×10^{-8}	1.3×10^{-8}
^{127m}Te	1.8×10^{-8}	1.9×10^{-8}
^{129}I	1.4×10^{-13}	1.5×10^{-13}
^{134}Cs	7.3×10^{-7}	7.3×10^{-7}
^{137}Cs	4.0×10^{-7}	4.1×10^{-7}
^{144}Ce	2.6×10^{-6}	2.5×10^{-6}
^{154}Eu		2.8×10^{-8}

TABLE 7.2.1-6. One-Year Doses and 70-Year Dose Commitments to the Maximum Individual from Minor Accident Releases During Rail Transport of Fuel Residues (rem)

Organ	Dose, rem: U Recycle, Pu in SHLW or PuO_2 Stored: 1-Year	70-Year	U and Pu Recycle: 1-Year	70-Year
Total body	1.9×10^{-6}	1.1×10^{-5}	1.9×10^{-6}	1.0×10^{-5}
Thyroid	3.2×10^{-7}	3.2×10^{-7}	3.4×10^{-7}	3.4×10^{-7}
Lung	9.8×10^{-5}	1.4×10^{-4}	9.8×10^{-5}	1.4×10^{-4}
Bone	1.5×10^{-5}	5.7×10^{-5}	1.5×10^{-5}	5.4×10^{-5}
Skin	6.5×10^{-8}	6.5×10^{-8}	6.6×10^{-8}	6.6×10^{-8}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

The largest organ dose, about 1 x 10^{-4} rem to the lung, is on the order of 10% of the nominal variation in annual dose received from naturally occurring sources at a given location and is expected to be without consequence.

An accident thought to be severe was identified and is described below. The consequences of this accident are believed to be less than those of Accident 5.2.1, whose analysis is substituted in lieu of a separate analysis for Accident 6.4.4.

Accident Number	Description
6.4.4	Fuel residue cask subjected to severe impact and fire

That accident results in breach of a canister containing 1340 kg of zirconium with 14% of the contained metal being exposed to the atmosphere; 1 x 10^{-6} of the exposed metal is entrained in the atmosphere. The expected release of radioactive material is given in *Table 7.2.1-7. The* various compaction options are not assumed to reduce the amount of material released. This accident has a postulated frequency of occurrence of 1 x 10^{-5} per year.

TABLE 7.2.1-7. Radionuclides Released to the Atmosphere from a Fuel Residue Cask Subjected to Severe Impact and Fire During Rail Transport

	Release, Ci	
Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	2.2 x 10^{-2}	2.2 x 10^{-2}
^{14}C	2.1 x 10^{-5}	2.1 x 10^{-5}
^{60}Co	3.5 x 10^{-2}	3.5 x 10^{-2}
^{90}Sr	1.1 x 10^{-2}	1.1 x 10^{-2}
^{95}Zr	2.9 x 10^{-2}	2.9 x 10^{-2}
^{106}Ru	3.3 x 10^{-2}	3.0 x 10^{-2}
^{125m}Te	4.2 x 10^{-4}	3.9 x 10^{-4}
^{127m}Te	7.5 x 10^{-5}	7.4 x 10^{-5}
^{134}Cs	2.1 x 10^{-2}	2.1 x 10^{-2}
^{137}Cs	1.6 x 10^{-2}	1.6 x 10^{-2}
^{144}Ce	4.2 x 10^{-2}	4.4 x 10^{-2}
^{238}Pu	9.6 x 10^{-4}	5.4 x 10^{-4}
^{239}Pu	6.3 x 10^{-5}	5.1 x 10^{-5}
^{241}Pu	3.2 x 10^{-2}	1.9 x 10^{-2}
^{242}Cm	1.7 x 10^{-3}	6.1 x 10^{-4}
^{244}Cm	1.3 x 10^{-3}	2.1 x 10^{-4}

Total-body doses to the maximum individual immediately after the accident and the 70-year One-year and 70-year dose commitments to the maximum individual are given in Table 7.2.1-8. The largest dose from this accident, about 4×10^{-2} rem to the lung, is about one-half the nominal annual dose received from naturally occurring sources.

TABLE 7.2.1-8. One-Year Dose and 70-Year Dose Commitment to Maximum Individual Resulting from the Severe Impact and Fire of a Fuel Residue Cask During Rail Transport

	Dose, rem			
	U Recycle, Pu in SHLW or PuO_2 Stored		U and Pu Recycle	
Organ	1-Year	70-Year	1-Year	70-Year
Total body	5.0×10^{-4}	8.1×10^{-3}	3.3×10^{-4}	4.7×10^{-3}
Thyroid	1.2×10^{-5}	1.2×10^{-5}	1.1×10^{-5}	1.1×10^{-5}
Lung	3.8×10^{-2}	7.4×10^{-2}	2.0×10^{-2}	3.7×10^{-2}
Bone	6.8×10^{-3}	1.4×10^{-1}	3.7×10^{-3}	7.3×10^{-2}
Skin	7.3×10^{-6}	7.3×10^{-6}	7.2×10^{-6}	7.2×10^{-6}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

Expected Consequences of Nonradiological Accidents. Rail shipment of fuel residues, depending on treatment option, will involve distances (in millions of kilometers) as shown in the following table:

	Year 2000	Peak Year	Total Through 2050
Packaging without compaction	2.9	3.2	144
Mechanical compaction	1.7	2.0	84
Compaction by melting	1.1	1.3	57

At a rate of 0.039 fatalities and 0.36 injuries per million kilometers the following consequences may be expected through the year 2050 as a result of shipping fuel residues or empty casks by rail:

	Fatalities	Injuries
Packaging without compaction	6	52
Mechanical compaction	3	31
Compaction by melting	2	21

Ecological Effects. No accidents or unusual events have been identified that would be detrimental to terrestrial or aquatic ecosystems.

REFERENCES FOR SECTION 7.2.1

1. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

7.2.2 Environmental Effects Related to Truck Transport of Fuel Residues (DOE/ET-0028 Sec. 6.4.2)

The reference mode for transporting fuel residues is by rail; however, fuel residues could also be shipped by truck. In the present design a truck would carry one container whereas a railcar would carry three containers. Although fuel residues are not currently being shipped, shipping time for truck is estimated at 7 cask-days/trip compared with 24 cask-days/trip for rail.

7.2.2.1 Resource Commitments Associated with Fabrication of Equipment

The conceptual truck transport container is a top-loading cylindrical cask with stainless steel liner and outer constructural walls and a lead gamma shield that will hold one canister. The materials committed to fabrication of fuel residue truck casks are:

	One Cask, MT	Total Required in Year 2000 (35 Casks), MT	Total Required in Peak Years 2010 to 2020 (48 Casks), MT
Stainless steel (SS)	4	140	190
Chromium (in SS)	0.7	25	34
Nickel (in SS)	0.3	11	14
Lead	15	525	720

These quantities do not include allowance for a special lightweight highway trailer, support systems, or other equipment. Resources required for a single cask are judged to be insignificant in terms of resource use. The total resources required in the years 2010 to 2020 are not likely to significantly affect U.S. industry when distributed over a period of 15 to 25 years.

7.2.2.2 Environmental Effects Related to Routine Operation

The routine shipment of fuel residues is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impacts of shipping fuel residues by truck.

Resource Commitments. Fuel requirements for truck transport are based on 2.2×10^4 MT-km/m^3 of diesel fuel.(1) For the 33 MT shipping cask and car, the fuel commitment is calculated based on an assumed shipping distance of 4800 km (round trip) between the FRP and the waste repository, multiplied by the number of shipments and divided by 670 km/m^3 of diesel fuel. The number of shipments required for each fuel residue treatment option are shown in Table 7.2.2-1. Table 7.2.2-2 gives commitments of diesel fuel necessary for transporting fuel residues by truck.

Transport Effluents. Each shipment of fuel residues will generate about 0.3 kJ/s (0.3 kW) of heat. Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with truck transport. Table 7.2.2-3 contains estimated average diesel engine emissions. No effluents will be released to ground or water.

Physical, Chemical, and Thermal Effects. Heat rejected during truck transport of fuel residues is five orders of magnitude less than the stationary facility heat load considered to have microclimatic effects. Both the head loads and combustion product releases amount to a small increment over total present releases associated with the trucking industry.

TABLE 7.2.2-1. Shipments of Fuel Residues by Truck from Fuel Reprocessing Plants to Repositories

	Packaging Without Treatment	Mechanical Compaction	Compaction by Melting
Year 2000	1,800	1,000	710
Peak years, 2010 to 2020	2,000	1,200	800
Total through year 2050	90,000	52,500	36,000

TABLE 7.2.2-2. Diesel Fuel Needed for Transporting Fuel Residues by Truck

	Packaging Without Treatment	Mechanical Compaction	Compaction by Melting
Year 2000, m^3/yr	1.2×10^4	7.2×10^3	4.7×10^3
Peak years, 2010 to 2020, m^3/yr	1.6×10^4	1.0×10^4	6.5×10^3
Total through year 2050, m^3	6.5×10^5	3.9×10^5	2.6×10^5

TABLE 7.2.2-3. Nonradioactive Pollutants Released by Trucks Shipping Fuel Residues in the Year 2000

		Total Releases of All Shipments Based on Packaging Without Treatment Option[a]		
Pollutant	Release Rate, MT/million km	Year 2000, MT	Peak Years, 2010 to 2020, MT/yr	Through Year 2050, MT
Carbon monoxide	40	350	380	17,000
Hydrocarbons	6.8	59	65	2,900
Nitrogen oxides	68	590	650	29,000
Sulfur oxides	4.8	41	46	2,100
Particulates	2.3	20	22	990

Source: Based on 1) emission factors in Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Energy Research and Development Administration, Washington, DC, June 1976, vol. 4, Table IX, G(A)-3, and 2) energy efficiency factors in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

a. Mechanical compaction would reduce emissions to about 60% of those shown; compaction by melting would reduce emissions to about 40% of those shown.

Radiological Effects. Under normal operating circumstances, no radioactive material will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from a passing truck shipment of fuel residues.

Dose is generally calculated for radiation workers (occupational exposure) and for members of the general population based on radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation doses to truck drivers were calculated assuming that the individual spends about 33 hr in the truck cab (either as driver or relief) and 1 hr at an average distance of 2 m from the cargo compartment per 1600 km traveled. Radiation dose rates in and around the truck are in accordance with Department of Transportation regulations. A truck driver on a 2400-km trip would be expected to receive a dose of 1.2×10^{-1} rem. The trucker is assumed to be involved in about 25 shipments per year and employed at the same job for 30 years. Thus, the truck driver receives about 3.0 rem annually and accumulates 90 rem during his career.

Doses received by members of the general population from direct radiation of a passing truck shipment of fuel residues were calculated based on the speed of the truck (50 km/hr, 24 hr/day), the distance of the shipment (2400 km), and the population density along the highway (40 persons/km^2). On a per kilometer basis the annual dose per shipment to the population was calculated to be 1.1×10^{-6} man-rem/km. For comparison, the annual dose to the same group from naturally occurring radiation was calculated to be about 4.0 man-rem/km.

Radiation dose to the maximum individual was calculated based on the individual's residence 30 m from the center of the highway. The dose received by the maximum individual would be 1.6×10^{-7} rem per shipment. The direct radiation doses to the maximum individual and general population are given in Table 7.2.2-4, along with the annual radiation dose to the transportation work force for each of the three transport options.

TABLE 7.2.2-4. Total-Body Doses Received from Direct Radiation of Fuel Residues Being Transported by Truck

Group	Waste Treatment: Packaging Without Compaction	Mechanical Compaction	Compaction by Melting
	Year 2000		
Maximum individual, rem/yr[a]	2.9×10^{-4}	1.6×10^{-4}	1.1×10^{-4}
Population, man-rem/yr[b]	4.8	2.6	1.9
Work force, man-rem/yr[c]	4.3×10^{2}	2.4×10^{2}	1.7×10^{2}
	Peak Years, 2010 to 2020		
Maximum individual, rem/yr[a]	3.2×10^{-4}	1.9×10^{-4}	1.3×10^{-4}
Population, man-rem/yr[b]	5.3	3.2	2.1
Work force, man-rem/yr[c]	4.8×10^{2}	2.9×10^{2}	1.9×10^{2}
	Through Year 2050		
Maximum individual, rem[a]	1.4×10^{-2}	8.4×10^{-3}	5.8×10^{-3}
Population, man-rem[b]	2.4×10^{2}	1.4×10^{2}	9.5×10^{1}
Work force, man-rem[c]	2.2×10^{4}	1.3×10^{4}	8.6×10^{3}

a. The assumption is made that all shipments follow the same route, thus the maximum individual is exposed to each shipment.
b. The annual dose to the population from naturally occurring sources along the transport route is 9.6×10^3 man-rem.
c. The assumption is made that two individuals are assigned to a truck and they alternate driving and resting.

Ecological Effects. Some particulates and gases will be released to the atmosphere from combustion of fossil fuels during normal truck shipments; however, these releases are not expected to be of ecological significance.

7.2.2.3 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with truck transport of fuel residues have been identified that could lead to releases of radioactive materials. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
6.2.9	Truck collision or overturn involves fuel residue cask
6.2.10	Truck collision or overturn and 30-min (or less) fire involves fuel residue cask
6.2.11	Undetected cask surface contamination washoff

No release of radioactive material was postulated for Accidents 6.2.9 and 6.2.10. Radioactive material released in Accident 6.2.11 is presented in Table 7.2.2-5. This accident is postulated to occur twice per year. One-year doses and 70-year dose commitments to the maximum individual, defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3, are presented in Table 7.2.2-6.

TABLE 7.2.2-5. Radionuclides Released to the Atmosphere from Minor Accidents During Truck Transport of Fuel Residues

Radionuclide	Release, Ci	
	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	4.8×10^{-10}	5.0×10^{-10}
^{85}Kr	1.1×10^{-8}	9.8×10^{-9}
^{90}Sr	7.4×10^{-8}	6.8×10^{-8}
^{90}Y	7.4×10^{-7}	6.8×10^{-8}
^{91}Y	1.1×10^{-7}	1.0×10^{-7}
^{95}Zr	1.9×10^{-7}	3.6×10^{-7}
^{95}Nb	3.6×10^{-7}	3.6×10^{-7}
^{106}Ru	3.7×10^{-7}	4.1×10^{-7}
^{125m}Te	3.1×10^{-9}	3.4×10^{-9}
^{127m}Te	4.6×10^{-9}	4.8×10^{-9}
^{129}I	3.6×10^{-14}	3.9×10^{-14}
^{134}Cs	1.9×10^{-7}	1.9×10^{-7}
^{137}Cs	1.0×10^{-7}	1.1×10^{-7}
^{144}Ce	6.7×10^{-7}	6.5×10^{-7}
^{154}Eu		7.0×10^{-9}

TABLE 7.2.2-6. One-Year Dose and 70-Year Dose Commitments to the Maximum Individual from Minor Accident Releases During Truck Transport of Fuel Residues

Organ	Dose, rem: U Recycle, Pu in SHLW or PuO_2 Stored, 1-Year	70-Year	U and Pu Recycle, 1-Year	70-Year
Total body	4.9×10^{-7}	2.8×10^{-6}	4.8×10^{-7}	2.6×10^{-6}
Thyroid	8.2×10^{-8}	8.2×10^{-8}	8.7×10^{-8}	8.7×10^{-8}
Lung	2.5×10^{-5}	3.5×10^{-5}	2.5×10^{-5}	3.5×10^{-8}
Bone	3.9×10^{-6}	1.5×10^{-5}	3.8×10^{-6}	1.4×10^{-5}
Skin	1.7×10^{-8}	1.7×10^{-8}	1.7×10^{-8}	1.7×10^{-8}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

The largest organ dose, about 2.5×10^{-5} rem to the lung, is less than 10% of the nominal variation in annual dose received from naturally occurring sources at a given location.

An accident thought to be severe was identified and is described below. The consequences of this accident are believed to be less than those of Accident 5.2.1, whose analysis is substituted in lieu of a separate analysis for Accident 6.4.4

Accident Number	Description
6.4.4	Fuel residue cask is subjected to severe impact and fire

The accident results in breach of a canister containing 1340 kg of zirconium with 14% of the metal being exposed to the atmosphere; 1×10^{-6} of the exposed material is entrained by the atmosphere. The expected release of radioactive material is given in Table 7.2.2-7. The various compaction options are not assumed to reduce the material released. This accident has a postulated frequency of occurrence of 0.2 per year.

Total-body doses to the maximum individual immediately after the accident and the 70-year dose commitment are given in Table 7.2.1-8. The largest dose from this accident, about 4×10^{-2} rem to the lung, is about one-half the nominal annual dose received from naturally occurring sources.

Expected Consequences of Nonradiological Accidents. Over the 70-year period ending in 2050 about 435 million km will have been traveled if fuel residues are packaged without treatment and are shipped by truck. At a rate of 0.44 injuries and 0.045 fatalities per million kilometers, the following consequences may be expected through the year 2050 as a result of shipping fuel residues or empty casks by truck:

	Fatalities	Injuries
Packaging without compaction	20	190
Mechanical compaction	12	110
Compaction by melting	6	76

TABLE 7.2.2-7. Radionuclides Released to the Atmosphere from a Fuel Residue Cask Subjected to Severe Impact and Fire During Truck Shipment

Radionuclide	Release, Ci: U Recycle, Pu in SHLW or PuO_2 Stored	Release, Ci: U and Pu Recycle
^{3}H	2.2×10^{-2}	2.2×10^{-2}
^{14}C	2.1×10^{-5}	2.1×10^{-5}
^{60}Co	3.5×10^{-2}	3.5×10^{-2}
^{90}Sr	1.1×10^{-2}	1.1×10^{-2}
^{95}Zr	2.9×10^{-2}	2.9×10^{-2}
^{106}Ru	3.3×10^{-2}	3.0×10^{-2}
^{125m}Te	4.2×10^{-4}	3.9×10^{-4}
^{127m}Te	7.5×10^{-5}	7.4×10^{-5}
^{134}Cs	2.1×10^{-2}	2.1×10^{-2}
^{137}Cs	1.6×10^{-2}	1.6×10^{-2}
^{144}Ce	4.2×10^{-2}	4.4×10^{-2}
^{238}Pu	9.6×10^{-4}	5.4×10^{-4}
^{239}Pu	6.3×10^{-5}	5.1×10^{-5}
^{241}Pu	3.2×10^{-2}	1.9×10^{-2}
^{242}Cm	1.7×10^{-3}	6.1×10^{-4}
^{244}Cm	1.3×10^{-3}	2.1×10^{-4}

TABLE 7.2.2-8. One-Year Dose and 70-Year Dose Commitment to Maximum Individual Resulting from the Severe Impact and Fire of a Fuel Residue Cask During Truck Transport

Organ	Dose, rem: U Recycle, Pu in SHLW or PuO_2 Stored: 1-Year	70-Year	U and Pu Recycle: 1-Year	70-Year
Total body	5.0×10^{-4}	8.1×10^{-3}	3.3×10^{-4}	4.7×10^{-3}
Thyroid	1.2×10^{-5}	1.2×10^{-5}	1.1×10^{-5}	1.1×10^{-5}
Lung	3.8×10^{-2}	7.4×10^{-2}	2.0×10^{-2}	3.7×10^{-2}
Bone	6.8×10^{-3}	1.4×10^{-1}	3.7×10^{-3}	7.3×10^{-2}
Skin	7.3×10^{-6}	7.3×10^{-6}	7.2×10^{-6}	7.2×10^{-6}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

Ecological Effects. No accidents or unusual events have been identified that would be detrimental to terrestrial or aquatic ecosystems.

REFERENCES FOR SECTION 7.2.2

1. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

7.2.3 Comparison of Environmental Effects Between Alternative Modes of Transporting Fuel Residues

Resource commitments necessary for construction of truck transport casks amount to about one-fourth of those necessary for rail transport casks. Rail casks with payload weigh about 65 MT; truck casks with payload weigh about 22 MT. The railcar weighs about 26 MT and the truck about 11 MT. The rail cask will carry three containers of fuel residues while the truck will carry one container.

If fuel residues are shipped by rail, total fuel required over the 70-year period ending in 2050 would amount to 1.9×10^5 m^3; if shipped by truck, 6.5×10^5 m^3 of diesel fuel would be needed.

Total nonradioactive pollutants released by these two modes of transportation are shown in Table 7.2.3-1.

TABLE 7.2.3-1. Nonradioactive Pollutants Released to the Atmosphere in Transporting Fuel Residues Through the Year 2050

Pollutant	Rail Transport, MT	Truck Transport, MT
Particulates	1.1×10^3	9.9×10^2
Sulfur oxides	2.2×10^3	2.1×10^3
Carbon monoxide	5.0×10^3	1.7×10^4
Hydrocarbons	3.4×10^3	2.9×10^3
Nitrogen oxides	1.3×10^4	2.9×10^4
Aldehydes	2.0×10^2	
Organic acids	2.6×10^2	

Doses to the maximum individual (assuming all shipments pass the same individual) and population are comparable. The dose to the truck transport worker is, however, on the order of 100 times larger than that of the rail transport worker. Radiation doses associated with routine transportation of fuel residues through the year 2050 are presented in Table 7.2.3-2.

TABLE 7.2.3-2. Radiation Doses Received from Routine Transport of Fuel Residues Through the Year 2050

Group	Rail	Truck
Maximum individual, rem	1.8×10^{-2}	1.4×10^{-2}
Population, man-rem	2.7×10^2	2.4×10^2
Transport work force, man-rem	3.6×10^2	2.2×10^4

Doses to the maximum individual from accidents involving either truck or rail transport are less than the annual dose from naturally occurring sources and are not significant in terms of health hazards. The same moderate accident was assigned to both modes of transport.

The trade-off for truck and rail transport is apparently between lower resource use for truck casks (which, if their constituents are not contaminated beyond cleanup, could be recycled) against about four times the consumption of diesel fuel. The additional consumption by trucks of about 5 x 10^5 m^3 of diesel fuel over 70 years may become significant.

7.3 TRANSPORTATION OF NON-HIGH-LEVEL TRANSURANIC WASTES

(DOE/ET-0028 Section 6.6)

7.3 TRANSPORTATION OF NON-HIGH-LEVEL TRANSURANIC WASTES (DOE/ET-0028 Sec. 6.6)

Non-high-level transuranic (TRU) wastes are generated at fuel reprocessing plants (FRP) and mixed-oxide fuel fabrication plants (MOX FFP). Such wastes represent a large volume of relatively low activity waste that requires transport.

Under a proposed rule,[(1)] commercially generated wastes that are contaminated with non-high-level TRU elements will be sent to Federal repositories for interim storage or permanent isolation. Because individual waste packages will exceed the 0.001-Ci limitation for Group I* radionuclides, all commercial non-high-level TRU waste shipments are presumed to be made in overpacks.

Prior to shipment, non-high-level TRU wastes are packaged in disposable containers. Most of the waste is assumed to be packaged in Department of Transportation (DOT) specification 17C 55-gal steel drums[(2)] and DOT specification 7A steel boxes[(3)] having dimensions of 1.2 x 1.8 x 1.8 m. High-efficiency particulate air (HEPA) filters too large to fit in 55-gal drums are assumed to be packaged in 80-gal drums. Shipments of non-high-level TRU-contaminated equipment and metal scraps that require shielding are assumed to be packaged in the canisters described in Section 7.2. for containment of fuel residues.

In the reference transportation mode, waste containers are transported by truck in overpacks, which may be shielded or unshielded depending on the radiation dose at the surface of the disposable container. For planning purposes, four shipment modes have been defined for non-high-level TRU wastes packaged in 55-gal drums. These shipment modes are described in Table 7.3.1-1.

TABLE 7.3.1-1. Reference Shipment Modes for Transport of 55-gal Drums of Non-High-Level Transuranic Wastes

Drum Surface Dose Rate, R/hr	Shipment Mode
<0.2	Unshielded exclusive-use van
0.2 to 1	Shielded exclusive-use van
1 to 10	Cask with equivalent shielding thickness of 5 cm lead and 2 cm steel
>10	Cask with equivalent shielding thickness of 10 cm lead and 2.5 cm steel

* Radioactive materials are classified for transportation purposes into one of seven transport groups according to their potential hazard if released to the environment. Transport Group I is the most restrictive. Plutonium and other transuranic elements are in this transport group.

Drums and boxes that do not require shielding are assumed to be transported in a Super Tiger®. A Super Tiger®, as Figure 7.3.1-1 illustrates, is a double-walled steel box with a fire-resistant polyurethane foam filler for shock and thermal insulation. Interior dimensions are 1.9 x 1.9 by 4.4 m. The empty weight is 6,800 kg, and the maximum payload is 13,600 kg. Three pallets containing twelve 55-gal drums per pallet (total of 36 drums), or three steel boxes, could be transported in a Super Tiger®. The overpack is loaded from one end in a horizontal position.

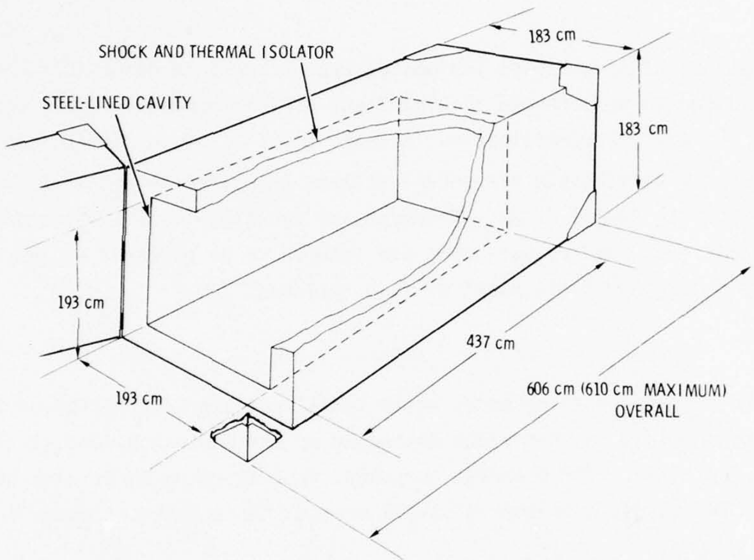

FIGURE 7.3.1-1. Super Tiger® Used for Transporting Non-High-Level Transuranic Wastes

Shielded vans licensed for these shipments are not available commercially, although shielded vans for low-specific-activity shipments of drummed waste are in commercial use. It is anticipated that a shielded van that meets packaging standards or a Super Tiger® type of overpack that incorporates some shielding could be constructed to transport drummed non-high-level TRU waste with surface dose rates in the range of 1 R/hr.

Truck casks that incorporate several inches of lead or other shielding material are commercially available. The capacity of shielded overpacks is typically less than that of unshielded overpacks. Container volume in shielded units must be limited so that overall package weights do not exceed truck weight limits. For this study, the reference cask with 6 in. equivalent lead shielding is postulated to have a capacity of fourteen 55-gal drums, and the reference cask with 12 in. equivalent lead shielding is postulated to have a capacity of six 55-gal drums.

7.3.1 Environmental Effects Associated with Rail Transport of Non-High-Level Transuranic Wastes (DOE/ET-0028 Sec. 6.6.2)

The information that follows is provided to form a basis for the evaluation of environmental impacts assuming that all non-high-level transuranic (TRU) wastes are transported by rail.

7.3.1.1 Resource Commitments Associated with Fabrication of Equipment

Non-high-level TRU wastes are packaged for rail transport in lined 55-gal (0.21 m^3) drums or in 1.2 x 1.8 x 1.8 m steel or plywood boxes that are polyethylene lined and fiberglass coated. The drums or boxes are placed in standard steel cargo containers* and transported in a modified railcar. The total capacity of the car is 72 standard drums or an equivalent net volume of boxes.

The materials needed for fabrication of the specially modified railcar and steel cargo containers, excluding the drums and boxes, are:

	One Cask, MT	Total Required in Year 2000, MT (18 Casks)	Total Required in Peak Year 2010, MT (39 Casks)
Stainless steel (SS)	16	290	620
Chromium (in SS)	2.9	52	110
Nickel (in SS)	1.3	23	49

These values are for the reference mode of combustible trash incineration followed by cement immobilization. If incineration is followed by bitumen immobilization the material commitments would be 0.61 of those listed. If combustibles are given minimum treatment and cement immobilization, the cask requirements would be 1.9 times those shown; if minimum treatment and bitumen immobilization, the cask requirements would be 1.6 times those shown. Materials required for cask construction are judged to be insignificant in terms of resource use.

7.3.1.2 Environmental Effects Related to Routine Operation

The routine shipment of non-high-level TRU waste is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impact of routine non-high-level TRU shipments by rail.

Resource Commitments. Fuel requirements for rail transport are based on 7.7 x 10^4 MT-km/m^3 of diesel fuel.[4] For the 91 MT shipping and vehicle cask, the fuel required is obtained from an assumed shipping distance of 4800 km (round trip) between the FRP or MOX FFP and the waste repository, multiplied by the number of shipments, and divided by 850 km/m^3 of diesel fuel. Fuel requirements are given in Table 7.3.1-2.

Transport Effluents. Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with rail transport. Table 7.3.1-3 gives estimated average locomotive emissions per unit distance traveled. Table 7.3.1-4 gives estimated releases of pollutants for various years. No effluents will be released to ground or water.

Physical, Chemical, and Thermal Effects. The combustion products are small fractional increases in the total emissions from all national rail transport; as such, the additional atmospheric effects are not considered significant.

*These containers are for convenience and are not a safety requirement.

TABLE 7.3.1-2. Diesel Fuel Requirements for Rail Shipment of Non-High-Level Transuranic Wastes

	Incineration with —		Minimum Treatment with —	
	Cementation	Bitumenization	Cementation	Bitumenization
Year 2000				
Shipments, no.	2.1×10^3	1.5×10^3	3.9×10^3	3.4×10^3
Diesel fuel, m^3/yr	1.2×10^4	8.5×10^3	2.2×10^4	1.9×10^4
Peak years, 2010 to 2025				
Shipments, no.	2.4×10^3	1.5×10^3	4.5×10^3	3.9×10^3
Diesel fuel, m^3/yr	1.4×10^4	8.5×10^3	2.5×10^4	2.2×10^4
Total through 2050				
Shipments, no.	1.0×10^5	6.1×10^4	1.9×10^5	1.6×10^5
Diesel fuel, m^3	5.7×10^5	3.4×10^5	1.0×10^6	9.0×10^5

TABLE 7.3.1-3. Average Emissions Attributable to Rail Transport of Non-High-Level Transuranic Wastes for the Year 2000

Pollutant	Releases per Shipment, MT/million km	Total Releases, MT/yr
Particulates	4.5	45
Sulfur oxides	9.1	91
Carbon monoxide	21	210
Hydrocarbons	15	150
Nitrogen oxides	56	560
Aldehydes	0.9	9
Organic acids	1.1	11

Radiological Effects. Under normal operating circumstances, no radioactive material will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from a passing rail shipment of non-high-level TRU waste.

Dose is generally calculated for radiation workers (occupational exposure) and for members of the general population based on the amount of radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation dose to railroad employees was calculated assuming that the employee spends up to 10 min in the vicinity of the waste shipment for an average exposure of 1×10^{-3} rem.* It is assumed that two railroad employees are so exposed per shipment. It was assumed that the employee is involved in about 20 shipments per year and that he is employed at the same job for 30 years. Thus, the railroad employee receives about 0.02 rem annually and accumulates 0.6 rem during his career.

* For calculation purposes, the shipment was assumed to be midway in the train, in which case the dose to an individual in either the engine or caboose would be on the order of 1×10^{-5} rem/shipment.

TABLE 7.3.1-4. Nonradioactive Pollutants Attributable to Rail Transport of Non-High-Level Transuranic Wastes (MT)

Pollutant	Incineration with — Cementation	Incineration with — Bitumenization	Minimum Treatment with — Cementation	Minimum Treatment with — Bitumenization
		Year 2000		
Particulates	4.5×10^1	2.7×10^1	8.6×10^1	7.2×10^1
Sulfur oxides	9.1×10^1	5.6×10^1	1.7×10^2	1.5×10^2
Carbon monoxide	2.1×10^2	1.3×10^2	4.0×10^2	3.4×10^2
Hydrocarbons	1.5×10^2	9.2×10^1	2.9×10^2	2.4×10^2
Nitrogen oxides	5.6×10^2	3.4×10^2	1.1×10^3	9.0×10^2
Aldehydes	9.0	5.5	1.7×10^1	1.4×10^1
Organic acids	1.1×10^1	6.7	2.1×10^1	1.8×10^1
		Peak Years, 2010 to 2025		
Particulates	5.2×10^1	3.2×10^1	9.9×10^1	8.3×10^1
Sulfur oxides	1.0×10^2	6.1×10^1	1.9×10^2	1.6×10^2
Carbon monoxide	2.4×10^2	1.5×10^2	4.6×10^2	3.8×10^2
Hydrocarbons	1.7×10^2	1.0×10^2	3.2×10^2	2.7×10^2
Nitrogen oxides	6.5×10^2	4.0×10^2	1.2×10^3	1.0×10^3
Aldehydes	1.0×10^1	6.1	1.9×10^1	1.6×10^1
Organic acids	1.3×10^1	7.9	2.5×10^1	2.1×10^1
		Total Through Year 2050		
Particulates	2.2×10^3	1.3×10^3	4.2×10^3	3.5×10^3
Sulfur oxides	4.4×10^3	2.7×10^3	8.4×10^3	7.0×10^3
Carbon monoxide	1.0×10^4	6.1×10^3	1.9×10^4	1.6×10^4
Hydrocarbons	7.2×10^3	4.4×10^3	1.4×10^4	1.2×10^4
Nitrogen oxides	2.7×10^4	1.6×10^4	5.1×10^4	4.3×10^4
Aldehydes	4.2×10^2	2.6×10^2	8.0×10^2	6.7×10^2
Organic acids	5.3×10^2	3.2×10^2	1.0×10^3	8.5×10^2

Source: Based on energy efficiency factors in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

Doses received by members of the general population from direct radiation of a passing rail shipment of non-high-level TRU waste were calculated based on the speed of the train (13 km/hr), distance of the shipment one way (2400 km), and the population density (40 persons/km^2) along the railroad right-of-way. On a per kilometer basis, the annual dose per shipment to the population was calculated to be 3.7×10^{-6} man-rem. For comparison, the annual dose to the same group from naturally occurring radiation was calculated to be 4.0 man-rem/km.

The calculation of direct radiation dose to the maximum individual was based on location of the individual's residence 30 m from the center of the railroad track. The annual dose to the maximum individual was calculated to be 5.8×10^{-7} rem per shipment. Doses received by the maximum individual, general population, and transport work force are given in Table 7.3.1-5.

TABLE 7.3.1-5. Direct Radiation Doses Received from Rail Shipment of Non-High-Level Transuranic Wastes

Group	Incineration with — Cementation	Incineration with — Bitumenization	Minimum Treatment with — Cementation	Minimum Treatment with — Bitumenization
	Year 2000			
Maximum individual,[a] rem/yr	1.2×10^{-3}	7.4×10^{-4}	2.3×10^{-3}	1.9×10^{-3}
Population,[b] man-rem/yr	1.9×10^{1}	1.1×10^{1}	3.5×10^{1}	3.0×10^{1}
Work force, man-rem/yr[c]	4.2	2.6	8.0	6.8
	Peak Years, 2010 to 2025			
Maximum individual,[c] rem/yr	1.4×10^{-3}	8.5×10^{-4}	2.6×10^{-3}	2.2×10^{-3}
Population, man-rem/yr[b]	2.1×10^{1}	1.3×10^{1}	4.0×10^{1}	3.4×10^{1}
Work force, man-rem/yr[c]	4.8	3.0	9.2	7.6
	Total Through Year 2050			
Maximum individual, rem[a]	5.8×10^{-2}	3.5×10^{-2}	1.1×10^{-1}	9.3×10^{-2}
Population, man-rem[b]	8.9×10^{2}	5.4×10^{2}	1.7×10^{3}	1.4×10^{3}
Work force, man-rem[c]	2.0×10^{2}	1.2×10^{2}	3.8×10^{2}	3.2×10^{2}

a. Assuming that each shipment passes the same individual.
b. Annual dose from naturally occurring sources to the same population along the transport route amounts to 9.6×10^{3} man-rem. Through the year 2050 this dose would be 6.7×10^{4} man-rem.
c. One brakeman is exposed to the waste each 200 km of a shipment.

Ecological Effects. Some particulates and gases will be released to the atmosphere from combustion of fossil fuels during normal locomotive operation; however, these releases are not expected to be of ecological significance.

7.3.1.3 Environmental Effects Related to Postulated Accidents

A number of minor accidents associated with rail transport of non-high-level TRU wastes have been identified that could lead to releases of radioactive materials. Scenarios for these accidents are provided in DOE/ET-0028.[5] The accidents are listed below.

Accident Number	Description
6.6.1	Train derailment involves non-high-level TRU waste container
6.6.2	Train derailment and 30 min (or less) fire involves non-high-level TRU waste container
6.6.3	Non-high-level TRU waste shipment made in improperly closed packages

No releases of radioactive material were postulated for Accidents 6.6.1 and 6.6.2. Radioactive material released in Accident 6.6.3 is presented in Table 7.3.1-6. This accident, postulated to occur once per year, assumes a release of respirable particles at ground level for 1 hr

without off-gas system control. The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3. Doses to the maximum individual resulting from releases of Accident 6.6.3 are given in Table 7.3.1-7.

TABLE 7.3.1-6. Radionuclides Released to the Atmosphere from Minor Accidents During Rail Transport of Non-High-Level Transuranic Wastes[a]

Radionuclide	Release, Ci: U Recycle, Pu in SHLW or PuO_2 Stored — FRP Waste	Release, Ci: U and Pu Recycle — FRP Waste	Release, Ci: U and Pu Recycle — MOX FFP Waste
^{3}H	1.4×10^{-7}	1.3×10^{-7}	
^{95}Zr	5.3×10^{-5}		
^{95}Nb	1.0×10^{-4}	2.4×10^{-6}	
^{106}Ru	1.1×10^{-4}	5.6×10^{-5}	
^{125m}Te	8.7×10^{-9}	7.4×10^{-9}	
^{127m}Te	1.3×10^{-8}	1.3×10^{-9}	
^{129}I	3.1×10^{-11}	3.3×10^{-11}	
^{238}Pu	9.6×10^{-7}	1.7×10^{-6}	
^{239}Pu	9.9×10^{-8}	1.1×10^{-7}	1.5×10^{-9}
^{241}Pu	3.4×10^{-5}	5.6×10^{-5}	6.6×10^{-7}
^{241}Am			4.2×10^{-6}

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

TABLE 7.3.1-7. One-Year Doses and 70-Year Dose Commitments to Maximum Individual from Minor Accident Releases During Rail Transport of Non-High-Level Transuranic Wastes[a]

Organ	Dose, rem: U Recycle, Pu in SHLW or PuO_2 Stored — FRP Waste — 1-Year	70-Year	U and Pu Recycle — FRP Waste — 1-Year	70-Year	U and Pu Recycle — MOX FFP Waste — 1-Year	70-Year
Total body	7.3×10^{-5}	1.4×10^{-3}	7.4×10^{-5}	2.2×10^{-3}	7.1×10^{-5}	3.0×10^{-3}
Thyroid	2.4×10^{-7}	2.4×10^{-7}	5.7×10^{-8}	5.8×10^{-8}	0	0
Lung	5.4×10^{-3}	1.0×10^{-2}	6.0×10^{-3}	1.3×10^{-2}	9.2×10^{-3}	2.3×10^{-2}
Bone	1.1×10^{-3}	3.0×10^{-2}	1.7×10^{-3}	4.9×10^{-2}	8.8×10^{-4}	4.2×10^{-2}
Skin	1.9×10^{-6}	1.9×10^{-6}	6.2×10^{-7}	6.2×10^{-7}	9.4×10^{-10}	9.4×10^{-10}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

One accident is postulated to release radioactive material in amounts larger than those released by minor accidents. It is classified as a severe accident and is listed below.

Accident Number	Description
6.6.4	Non-high-level TRU waste container is subjected to severe impact and fire

This accident results in the release of 1×10^{-5} of the contained non-high-level TRU material in the form of respirable particles at ground level for 2 hr without off-gas system control. The expected release of radioactive material is given in Table 7.3.1-8. One-year doses and 70-year dose commitments to the maximum individual resulting from severe accident releases are given in Table 7.3.1-9. This accident has a postulated frequency of occurrence of 1×10^{-5} per year.

TABLE 7.3.1-8. Releases to the Atmosphere from a Non-High-Level Transuranic Waste Container Subjected to Severe Impact and Fire During Rail Transport[a]

	Release, Ci		
	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle	
Radionuclide	FRP Waste	FRP Waste	MOX FFP Waste
^{3}H	1.4×10^{-4}	1.3×10^{-4}	
^{90}Sr	2.1×10^{-4}	1.9×10^{-4}	
^{95}Zr	5.3×10^{-2}		
^{95}Nb	1.0×10^{-1}	2.4×10^{-3}	
^{106}Ru	1.1×10^{-1}	5.9×10^{-2}	
^{125m}Te	8.7×10^{-6}	7.4×10^{-6}	
^{127m}Te	1.3×10^{-5}	1.3×10^{-6}	
^{129}I	3.1×10^{-8}	3.3×10^{-8}	
^{137}Cs	2.9×10^{-4}	2.9×10^{-4}	
^{238}Pu	9.6×10^{-4}	1.7×10^{-3}	
^{239}Pu	9.0×10^{-5}	1.1×10^{-4}	1.5×10^{-6}
^{241}Pu	3.4×10^{-2}	5.6×10^{-2}	
^{241}Am			4.2×10^{-3}

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

TABLE 7.3.1-9. One-Year Doses and 70-Year Dose Commitments to Maximum Individual from Non-High-Level Transuranic Waste Container Subjected to Severe Impact and Fire During Rail Transport[a]

	Dose, rem					
	U Recycle, Pu in SHLW or PuO_2 Stored		U and Pu Recycle			
	FRP Waste		FRP Waste		MOX FFP Waste	
Organ	1-Year	70-Year	1-Year	70-Year	1-Year	70-Year
Total body	7.3×10^{-2}	1.4	7.5×10^{-2}	2.3	7.1×10^{-2}	3.0
Thyroid	2.3×10^{-4}	2.3×10^{-4}	5.8×10^{-5}	5.8×10^{-5}	0	0
Lung	5.4	1.0×10^{1}	6.0	1.3×10^{1}	9.0	2.3×10^{1}
Bone	1.1	2.9×10^{1}	1.7	4.9×10^{1}	8.8×10^{-1}	4.2×10^{1}
Skin	2.0×10^{-3}	2.0×10^{-3}	6.2×10^{-4}	6.2×10^{-4}	9.4×10^{-7}	9.4×10^{-7}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

Expected Consequences of Nonradiological Accidents. Through the year 2050 transport of non-high-level TRU wastes by rail would involve about 480 million km of travel. Injuries and fatalities associated with nonradiological accidents were calculated using an injury rate of 0.36 per million kilometers of travel and a fatality rate of 0.039 per million kilometers. The results of these calculations are given in Table 7.3.1-10.

TABLE 7.3.1-10. Injuries and Fatalities Associated with Nonradiological Accidents Resulting from Rail Transport of Non-High-Level Transuranic Wastes Through the Year 2050

Treatment Option	Injuries	Fatalities
Incineration with —		
Cementation	170	19
Bitumenization	100	11
Minimum treatment with —		
Cementation	330	36
Bitumenization	280	30

Ecological Effects. No accidents or unusual events have been identified that would result in detrimental effects to terrestrial or aquatic ecosystems.

REFERENCES FOR SECTION 7.3.1

1. "Proposed Rule-Making on Transuranic Waste Disposal, Proposed Amendment to 10 CFR 20," Federal Register 39: 30164, Aug. 21, 1974.

2. Title 49, Code of Federal Regulations, Part 178.115 (49 CFR 178.115).

3. Title 49, Code of Federal Regulations, Part 178.350 (49 CFR 178.350).

4. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

5. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

7.3.2 Environmental Effects Associated with Truck Transport of Non-High-Level Transuranic Wastes (DOE/ET-0028 Sec. 6.6.1)

The volume of non-high-level transuranic (TRU) wastes to be transported is dependent on the method of waste generation and treatment. Two classes of wastes are included — general trash and combustible waste, and wet wastes and particulate solids. The combinations of waste treatments discussed in this analysis are incineration followed by cement immobilization of incineration residues and all other wet wastes and particulate solids, incineration followed by bitumen immobilization, minimum treatment of combustible wastes plus cement immobilization, and minimum treatment plus bitumen immobilization. The information that follows is provided to form a basis for evaluating the environmental effects associated with truck transport of non-high-level TRU wastes.

7.3.2.1 Resource Commitments Associated with Fabrication of Equipment

Non-high-level TRU wastes are packaged for truck transport in lined 55-gal (0.21 m^3) drums or in 1.2 x 1.8 x 1.8 m steel or plywood boxes that are polyethylene lined and fiberglass coated. The drums or boxes are placed in an unshielded overpack with capacity for 36 drums or an equivalent volume of boxes. The transporter is a special low-boy trailer.

Materials needed for fabrication of the secondary waste transportation containers (casks) used for truck transport are:

	One Cask, MT	Total Required in Year 2000, MT (63 Casks)	Total Required in Peak Years 2010 to 2025, MT (77 Casks)
Stainless steel (SS)	7	440	540
Chromium (in SS)	1.3	82	100
Nickel (in SS)	0.6	38	46

These quantities do not include allowances for the highway trailers, support systems, or other equipment. Resources required for construction of a single shipment cask are judged to be insignificant in terms of resource use. Total resource requirements in the years 2010 to 2025 are also judged to be insignificant in terms of impact on other users.

7.3.2.2 Environmental Effects Related to Routine Operation

The routine shipment of non-high-level TRU wastes is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the environmental effects associated with truck transport of these wastes.

Resource Commitments. Fuel requirements for truck transport are based on 2.2×10^4 MT-km/m^3 of diesel fuel.[1] For the 23 MT shipping cask and vehicle, the fuel required is obtained from an assumed shipping distance of 4800 km round trip between the FRP and the waste repository, multiplied by the number of shipments, and divided by 980 km/m^3 of diesel fuel. Fuel requirements are presented in Table 7.3.2-1.

TABLE 7.3.2-1. Diesel Fuel Requirements for Transporting Non-High-Level Transuranic Wastes by Truck

	Incineration with —		Minimum Treatment with —	
	Cementation	Bitumenization	Cementation	Bitumenization
Year 2000				
Shipments, no.	4.2×10^3	3.0×10^3	7.8×10^3	6.4×10^3
Diesel fuel, m^3/yr	2.1×10^4	1.5×10^4	3.8×10^4	3.2×10^4
Peak years, 2010 to 2025				
Shipments, no.	4.8×10^3	3.0×10^3	9.0×10^3	7.8×10^3
Diesel fuel, m^3/yr	2.4×10^4	1.5×10^4	4.4×10^4	3.8×10^4
Total through 2050				
Shipments, no.	2.0×10^5	1.2×10^5	3.8×10^5	3.2×10^5
Diesel fuel, m^3	9.8×10^5	5.9×10^5	1.9×10^6	1.6×10^6

Transport Effluents. Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with truck transport. The estimated annual diesel fuel engine emissions are given in Table 7.3.2-2 for each of four waste immobilization options. There will be no release to ground or water.

Physical, Chemical, and Thermal Effects. The atmospheric releases from truck transport of non-high-level TRU wastes are small increments of those from the total trucking industry; therefore, no measurable atmospheric effects are postulated.

Radiological Effects. Under normal operating circumstances, no radioactive materials will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from a passing truck shipment of non-high-level TRU waste.

Dose is generally calculated for radiation workers (occupational exposure) and for members of the general population based on the amounts of radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation dose to truck drivers was calculated assuming that the driver spends 33 hr in the cab of the truck (either as driver or as relief) and 1 hr outside the truck at an

TABLE 7.3.2-2. Nonradioactive Pollutants Attributable to Truck Transport of Non-High-Level Transuranic Wastes (MT)

Pollutant	Incineration with — Cementation	Incineration with — Bitumenization	Minimum Treatment with — Cementation	Minimum Treatment with — Bitumenization
		Year 2000		
Carbon monoxide	8.1×10^2	5.8×10^2	1.5×10^3	1.2×10^3
Hydrocarbons	1.4×10^2	9.8×10^1	2.5×10^2	2.1×10^2
Nitrogen oxides	1.4×10^3	9.8×10^2	2.5×10^3	2.1×10^3
Sulfur oxides	9.7×10^1	6.9×10^1	1.8×10^2	1.5×10^2
Particulates	4.6×10^1	3.3×10^1	8.6×10^1	7.1×10^1
		Peak Years, 2010 to 2025		
Carbon monoxide	9.2×10^2	5.8×10^2	1.7×10^3	1.5×10^3
Hydrocarbons	1.6×10^2	9.8×10^1	2.9×10^2	2.5×10^2
Nitrogen oxides	1.6×10^3	9.8×10^2	2.9×10^3	2.5×10^3
Sulfur oxides	1.1×10^2	6.9×10^1	2.1×10^2	1.8×10^2
Particulates	5.3×10^1	3.3×10^1	9.9×10^1	8.6×10^1
		Total Through Year 2050		
Carbon monoxide	3.8×10^4	2.3×10^4	7.3×10^4	6.1×10^4
Hydrocarbons	6.5×10^3	3.9×10^3	1.2×10^4	1.0×10^4
Nitrogen oxides	6.5×10^4	3.9×10^4	1.2×10^5	1.0×10^5
Sulfur oxides	4.6×10^3	2.8×10^3	8.8×10^3	7.4×10^3
Particulates	2.2×10^3	1.3×10^3	4.2×10^3	3.5×10^3

Source: Based on emission factors in Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Energy Research and Development Administration, Washington, DC, June 1976, vol. 4, Table IX, G(A)-3, and energy efficiency factors in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

average distance of 2 m from the cargo compartment per 1600 km driven. For a 2400-km shipment, a truck driver would be assumed to receive a dose of 1.2×10^{-1} rem. It is further assumed that the truck driver makes about 25 shipments per year and is employed at the same job for 30 years, thus accumulating 2.9 rem annually and 88 rem during his career.

Doses received by members of the general population from direct radiation of a passing truck shipment of non-high-level TRU waste were calculated based on the speed of the truck (50 km/hr) and the population density (40 persons/km^2) along the highway. On a per kilometer basis the annual dose per shipment to the population was calculated to be 1.1×10^{-6} man-rem. For comparison, the annual dose to the same group from naturally occurring radiation was calculated to be 4.0 man-rem/km.

The calculation of direct radiation dose to the maximum individual was based on location of the individual's residence 30 m from the center of the highway. The dose received by the maximum individual would be 1.6×10^{-7} rem per shipment. Doses received by the maximum individual, general population, and transport work force for all four waste immobilization options are given in Table 7.3.2-3.

TABLE 7.3.2-3. Direct Radiation Doses Received from Truck Shipment of Non-High-Level Transuranic Wastes

Group	Incineration with — Cementation	Incineration with — Bitumenization	Minimum Treatment with — Cementation	Minimum Treatment with — Bitumenization
	Year 2000			
Maximum individual,[a] rem/yr	6.7×10^{-4}	4.1×10^{-4}	1.3×10^{-3}	1.1×10^{-3}
Population,[b] man-rem/yr	1.1×10^{1}	6.7	2.1×10^{1}	1.8×10^{1}
Work force,[c] man-rem/yr	1.0×10^{3}	6.1×10^{2}	1.9×10^{3}	1.6×10^{3}
	Peak Years, 2010 to 2025			
Maximum individual, rem/yr	7.7×10^{-4}	4.7×10^{-4}	1.5×10^{-3}	1.2×10^{-3}
Population, man-rem/yr	1.3×10^{1}	7.7	2.5×10^{1}	2.1×10^{1}
Work force, man-rem/yr	1.2×10^{3}	7.0×10^{2}	2.2×10^{3}	1.8×10^{3}
	Total Through Year 2050			
Maximum individual, rem	3.2×10^{-2}	2.0×10^{-2}	6.1×10^{-2}	5.1×10^{-2}
Population, man-rem	5.3×10^{2}	3.2×10^{2}	1.0×10^{3}	8.4×10^{2}
Work force, man-rem	4.8×10^{4}	2.9×10^{4}	9.1×10^{4}	7.7×10^{4}

a. Assuming that each shipment passes the same individual.
b. Annual dose to the same population from naturally occurring sources along the transport route amounts to 9.6×10^{3} man-rem. Through the year 2050 this dose would be 6.7×10^{4} man-rem.
c. It is assumed that two individuals are assigned to a truck and that they alternate driving and resting.

Ecological Effects. Some gases and particulates will be released to the atmosphere from combustion of fossil fuels during normal trucking operations; however, these releases are not expected to be of ecological significance.

7.3.2.3 Environmental Effects Related to Postulated Accidents

A number of minor accidents associated with truck transport of non-high-level TRU wastes have been identified that could lead to releases of radioactive materials. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
6.6.1	Truck collision or overturn accident involves non-high-level TRU waste container
6.6.2	Truck collision or overturn accident and 30 min (or less) fire involves non-high-level TRU waste container
6.6.3	Non-high-level TRU waste shipment made in improperly closed packages

No releases of radioactive material were postulated for Accidents 6.6.1 and 6.6.2. Radioactive material released in Accident 6.6.3 is presented in Table 7.3.2-4. This accident assumes that respirable particles are released at ground level for 1 hr without off-gas control. The postulated frequency of occurrence is once per year. One-year doses and 70-year dose commitments

to the maximum individual resulting from releases of Accident 6.6.3 are given in Table 7.3.2-5. The maximum individual is defined to be a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m.

TABLE 7.3.2-4. Radionuclides Released to the Atmosphere from Minor Accidents During Truck Transport of Non-High-Level Transuranic Wastes[a]

	Release, Ci		
	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle	
Radionuclide	FRP Waste	FRP Waste	MOX FFP Waste
^{3}H	1.4×10^{-7}	1.3×10^{-7}	
^{90}Sr	2.1×10^{-7}	1.9×10^{-7}	
^{95}Zr	5.3×10^{-5}	1.0×10^{-6}	
^{95}Nb	1.0×10^{-4}	2.4×10^{-6}	
^{106}Ru	1.1×10^{-4}	5.9×10^{-5}	
^{125m}Te	8.7×10^{-9}	7.4×10^{-9}	
^{127m}Te	1.3×10^{-8}	1.3×10^{-9}	
^{129}I	3.1×10^{-11}	3.3×10^{-11}	
^{134}Cs		3.3×10^{-11}	
^{137}Cs		2.9×10^{-7}	
^{238}Pu	9.6×10^{-7}	1.7×10^{-6}	
^{239}Pu	9.0×10^{-8}	1.1×10^{-7}	1.5×10^{-9}
^{240}Pu	1.4×10^{-7}	2.3×10^{-7}	
^{241}Pu	3.4×10^{-5}	5.6×10^{-5}	6.6×10^{-7}
^{241}Am			4.2×10^{-6}

Note: Waste immobilization options are assumed not to influence releases.
a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

One accident was postulated to release radioactive material in amounts larger than those released by minor accidents. It is classified as a severe accident and is listed below.

Accident Number	Description
6.6.4	Non-high-level TRU waste container is subjected to severe impact and fire

This accident results in the release of 10^{-15} of the contained non-high-level TRU material in the form of respirable particles at ground level for 2 hr without off-gas system control. The expected release of radioactive material is given in Table 7.3.2-6. One-year doses and 70-year dose commitments to the maximum individual resulting from severe accident releases are given in Table 7.3.2-7.

TABLE 7.3.2-5. One-Year Doses and 70-Year Dose Commitments to Maximum Individual from Minor Accident Releases During Truck Transport of Non-High-Level Transuranic Wastes[a]

Organ	Dose, rem: U Recycle, Pu in SHLW or PuO_2 Stored, FRP Waste, 1-Year	70-Year	U and Pu Recycle: FRP Waste, 1-Year	70-Year	MOX FFP Waste, 1-Year	70-Year
Total body	7.3×10^{-5}	1.4×10^{-3}	7.4×10^{-5}	2.2×10^{-3}	7.1×10^{-5}	3.0×10^{-3}
Thyroid	2.4×10^{-7}	2.4×10^{-7}	5.7×10^{-8}	5.8×10^{-8}	0	0
Lung	5.4×10^{-3}	1.0×10^{-2}	6.0×10^{-3}	1.3×10^{-2}	9.2×10^{-3}	2.3×10^{-2}
Bone	1.1×10^{-3}	3.0×10^{-2}	1.7×10^{-3}	4.9×10^{-2}	8.8×10^{-4}	4.2×10^{-2}
Skin	1.9×10^{-6}	1.9×10^{-6}	6.2×10^{-7}	6.2×10^{-7}	9.4×10^{-10}	9.4×10^{-10}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

TABLE 7.3.2-6. Releases to the Atmosphere from a Non-High-Level Transuranic Waste Container Subjected to Severe Impact and Fire During Truck Transport[a]

Radionuclide	Release, Ci: U Recycle, Pu in SHLW or PuO_2 Stored, FRP Waste	U and Pu Recycle: FRP Waste	MOX FFP Waste
^{3}H	1.4×10^{-4}	1.3×10^{-4}	
^{90}Sr	2.1×10^{-4}	1.9×10^{-4}	
^{95}Zr	5.0×10^{-2}		
^{95}Nb	1.1×10^{-1}	2.4×10^{-3}	
^{106}Ru	1.3×10^{-1}	5.9×10^{-2}	
^{125m}Te	8.7×10^{-6}	7.4×10^{-6}	
^{127m}Te	1.3×10^{-5}	1.3×10^{-6}	
^{129}I	3.1×10^{-8}	3.3×10^{-8}	
^{137}Cs	2.9×10^{-6}	2.9×10^{-4}	
^{238}Pu	9.6×10^{-4}	1.7×10^{-3}	
^{239}Pu	9.0×10^{-5}	1.1×10^{-4}	1.5×10^{-6}
^{241}Pu	3.4×10^{-2}	5.6×10^{-2}	
^{241}Am			4.2×10^{-3}

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

TABLE 7.3.2-7. One-Year Doses and 70-Year Dose Commitments to Maximum Individual from Non-High-Level Transuranic Waste Container Subjected to Severe Impact and Fire During Truck Transport[a]

	Dose, rem					
	U Recycle, Pu in SHLW or PuO_2 Stored		U and Pu Recycle			
	FRP Waste		FRP Waste		MOX FFP Waste	
Organ	1-Year	70-Year	1-Year	70-Year	1-Year	70-Year
Total body	7.3×10^{-2}	1.4	7.5×10^{-2}	2.3	7.1×10^{-2}	3.0
Thyroid	2.3×10^{-4}	2.3×10^{-4}	5.8×10^{-5}	5.8×10^{-5}	0	0
Lung	5.4	1.0×10^{1}	6.0	1.3×10^{1}	9.0	2.3×10^{1}
Bone	1.1	2.9×10^{1}	1.7	4.9×10^{1}	8.8×10^{-1}	4.2×10^{1}
Skin	2.0×10^{-3}	2.6×10^{-3}	6.2×10^{-4}	6.2×10^{-4}	9.4×10^{-7}	9.4×10^{-7}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

a. For uranium recycle, non-high-level transuranic wastes are shipped from the fuel reprocessing plant (FRP) and in the case of plutonium recycle, from the mixed-oxide fuel fabrication plant (MOX FFP) and the FRP.

Expected Consequences of Nonradiological Accidents. Injuries and fatalities associated with nonradiological accidents were calculated using an injury rate of 0.44 per million kilometers traveled and a fatality rate of 0.045 per million kilometers traveled. The results of these calculations for the 70-year period ending 2050 are presented in Table 7.3.2-8.

TABLE 7.3.2-8. Injuries and Fatalities Associated with Nonradiolcgical Accidents Resulting from Truck Transport of Non-High-Level Transuranic Wastes Through the Year 2050

Treatment Option	Distance, Million km	Injuries	Fatalities
Incineration with —			
Cementation	960	420	43
Bitumenization	580	260	26
Minimum treatment with —			
Cementation	1800	790	81
Bitumenization	1500	660	78

Ecological Effects. No accidents or unusual events have been identified that would result in significant effects to terrestrial or aquatic ecosystems.

REFERENCES FOR SECTION 7.3.2

1. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Energy Research and Development Administration, Washington, DC, in press.

7.3.3 Comparison of Environmental Effects Between Truck and Rail Shipment of Non-High-Level Transuranic Wastes

The reference rail cask holds the equivalent of twice the amount of non-high-level TRU wastes held by the reference truck cask. Substantially equal amounts of resource materials are needed for construction of rail or truck casks to transport equal quantities of waste.

Over the 70-year period ending in 2050 about $9.8 \times 10^5\ m^3$ of diesel fuel will be required for truck transport of non-high-level TRU wastes whereas rail transport will consume $5.7 \times 10^5\ m^3$. Thus, a reduction of about $4.1 \times 10^5\ m^3$ of diesel fuel could result from rail transport of non-high-level TRU wastes.

Pollutants released are not sufficiently different to be noteworthy.

The annual dose to the population from passing shipments was about 19 man-rem for rail shipment and about 11 man-rem for truck shipment. Although the train carries twice as much non-high-level TRU wastes, the speed is about one quarter that of the truck; thus, population doses from truck transport are on the order of half those from rail transport. The doses are not important in either case since they add only about 0.1% to dose from naturally occurring sources.

The dose to the rail transportation work force is on the order of 100 man-rem for the 70-year period ending in 2050 compared with 48,000 man-rem from truck transport for the same period. In terms of dose to the transport worker rail transport clearly results in a smaller impact.

In terms of traffic accidents about 160 injuries could be expected in rail transport over the 70-year period compared with 420 for truck transport. About 19 fatalities would be expected from train accidents and about 43 fatalities from truck accidents.

Doses from accidents associated with rail or truck transport are essentially negligible and offer little basis for comparison.

Within the framework of this analysis, rail transport, even at only a 2:1 carrying capacity, would appear to have distinct environmental advantages over truck transport of non-high-level TRU wastes.

7.4 TRANSPORTATION OF PLUTONIUM OXIDE

(DOE/ET-0028 Section 6.5)

7.4 TRANSPORTATION OF PLUTONIUM OXIDE (DOE/ET-0028 Sec. 6.5)

Shipments of plutonium are currently made by exclusive-use closed van, and this practice is expected to continue as the primary shipping mode. All shipments with more than 2 kg of plutonium must be made in accordance with Nuclear Regulatory Commission approved transport plans that provide for the physical protection of special nuclear material in transit.[1]

Shipping containers currently available are adequate for those forms of plutonium that require little or no shielding and that have a relatively low rate of heat generation. A recently developed container[2] (the Allied General Nuclear Services PPP-1 shipping container) is used as the basis for plutonium shipping information contained in this report. It incorporates gamma and neutron shielding and has a greater heat dissipation capacity than available in present packaging. The PPP-1 container can transport 32 kg of plutonium oxide powder in four annular canisters that are sealed inside a primary pressure vessel. The pressure vessel is shipped in a special overpack that provides radiation shielding and protection against fire and impact. The pressure vessel and overpack are shown schematically in Figure 7.4.1-1.

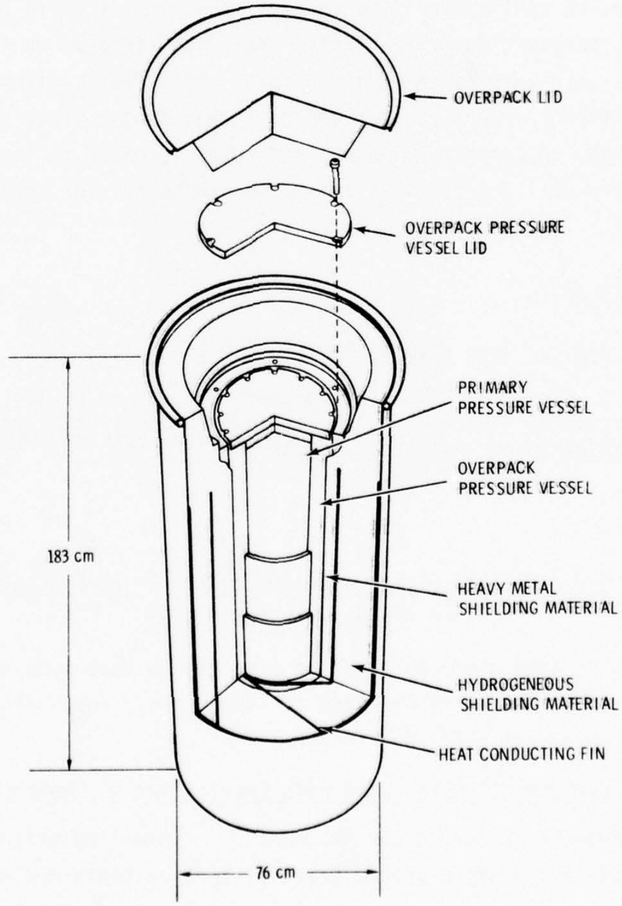

FIGURE 7.4.1-1. Plutonium Oxide Shipping Container

Canisters that contain the plutonium oxide powder are designed with an annular powder volume that will limit centerline temperatures. A vent on each canister allows gases such as water vapor or radiolytic decomposition products of water to escape from the canister while providing particulate filtration to contain the oxide powder. The primary pressure vessel has a design pressure of 1.6×10^6 Pa.

Gamma shielding for the overpack is provided by a lead annulus. Neutron shielding is provided by 20 cm of solid organic material sandwiched between the inner and outer walls of the overpack. Impact protection from both drop and puncture is also provided by the neutron shield material. The calculated heat dissipation capability of the cask under licensing conditions is 621 J/s (621 W). The overpack is fabricated from stainless steel and has outer dimensions of 76 cm in diameter by 1.83 m high. Total weight of a container and contents is about 1640 kg.

7.4.1 Rail Transport of Plutonium Oxide

Conceptually, plutonium oxide could be shipped from the reprocessing plant to a Federal waste storage facility by rail. Current thinking favors truck transport, however, based on safeguards considerations. Since neither safeguard procedures nor casks designed for rail transport are available, no analysis will be made of transport of waste plutonium oxide by rail. It is suggested, however, that if shipping casks and vehicles on the order of several hundred thousand pounds were used (such as in shipping spent fuel), diversion of the plutonium oxide might be more difficult from a railcar and cask than from a truck and cask. On the other hand, resources committed, pollutants released, and doses received by the work force and population are all relatively small, which may obviate the incentive for their reduction through fewer shipments by rail.

REFERENCES FOR SECTION 7.4.1

1. Title 10, Code of Federal Regulations, Part 73 (10 CFR 73).

2. R. E. Best and J. L. Ridihalgh, "The Development, Design and Evaluation of a Packaging for the Transportation of Plutonium." Proceedings of the Fourth International Symposium on the Packaging and Transportation of Radioactive Materials, CONF-740901, Miami Beach, FL, September 1974.

7.4.2 Environmental Effects Related to the Truck Transport of Plutonium Oxide

The transport of plutonium oxide by truck is expected to have some effects on the environment. The information that follows is provided to form a basis for evaluating the environmental impact of transporting plutonium oxide by truck.

7.4.2.1 Resource Commitments Associated with Fabrication of Equipment

Plutonium oxide powder is packaged for shipment in thin-walled stainless steel canisters. The canisters are placed in a primary pressure vessel that is contained within an overpack.

Materials needed for construction of the secondary waste transportation containers (casks), shielded overpack, and secondary pressure vessel are:

	One Container, MT	Total Required in Year 2000 (42 Casks), MT	Total Required in Peak Years 2010 to 2020 (63 Casks), MT
Stainless steel (SS)	0.50	21	30
Chromium (in SS)	0.09	3.8	5.4
Nickel (in SS)	0.04	1.7	2.4
Lead	0.50	21	30
Other	0.50	21	30

These quantities do not include allowances for highway trailers, support systems, plutonium oxide canisters, primary pressure vessels, or other equipment. These quantities are not considered to be significant in terms of resource use.

7.4.2.2 Environmental Effects Related to Routine Operation

The routine shipment of plutonium oxide is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impact of shipping plutonium oxide by truck.

Resource Commitments. Fuel requirements for truck transport are based on 2.2×10^4 MT-km/m^3 of diesel fuel.[1] For the 32 MT shipping cask and vehicle the fuel required is obtained from an assumed shipping distance of 4800 km round trip between the FRP and the retrievable waste storage facility, multiplied by the number of shipments, and divided by 700 km/m^3 of diesel fuel. Fuel requirements are as follows:

	Shipments	Diesel Fuel
Year 2000	219	1,500 m^3/yr
Peak years, 2010 to 2020	280	1,900 m^3/yr
Through year 2050	11,000	75,000 m^3

Transport Effluents. The heat generated by the plutonium in each shipment will be 5.6 kJ/s (5.6 kW). Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with truck transport. Table 7.4.2-1 gives estimated average diesel engine emissions. No effluents will be released to ground or water.

Physical, Chemical, and Thermal Effects. Heat rejected during truck transport of plutonium is four orders of magnitude less than stationary facility heat loads considered to have only microclimatic effects. Both heat loads and combustion product releases amount to a small increment over total present releases associated with truck transport.

Radiological Effects. Under normal operating circumstances, no radioactive materials will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from passing truck shipments of plutonium.

Dose is generally calculated for radiation workers (occupational exposure) and for members of the general public based on amounts of radioactive material released from nuclear facilities.

TABLE 7.4.2-1. Nonradioactive Pollutants Attributable to Truck Transport of Plutonium Oxide

Pollutant	Releases Rate MT/million km	All Shipments, MT Year 2000	Peak Year	Through 2050
Carbon monoxide	4.0	42	54	2100
Hydrocarbons	6.8	7.2	9.1	360
Nitrogen oxides	6.8	72	91	3600
Sulfur oxides	4.8	5.1	6.5	250
Particulates	2.3	2.4	3.1	120

Source: Based on 1) emission factors in Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Energy Research and Development Administration, Washington, DC, June 1976, vol. 4, Table IX, G(A)-3, and 2) energy efficiency factors in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation doses to truck drivers were calculated assuming that the driver spends 33 hr in the cab of the truck and 1 hr outside the truck at an average distance of 2 m from the cargo compartment per 1600 km driven. For a 2400-km shipment, a truck driver would be expected to receive a dose of about 1.2×10^{-1} rem. It is further assumed that the truck driver makes about 25 shipments per year and that he is employed at the same job for 30 years, thus accumulating 2.9 rem annually and 88 rem during his career.

The doses received by members of the general population from direct radiation of a passing truck shipment of plutonium were calculated based on the speed of the truck (50 km/hr), the distance of the shipment (2400 km), and the population density (40 persons/km^2) along the highway. On a per kilometer basis, the annual dose per shipment to the population was calculated to be 2.5×10^{-6} man-rem/km. For comparison, the annual dose to the same group from naturally occurring radiation was calculated to be 4.0 man-rem/km.

The calculation of direct radiation dose to the maximum individual was based on location of that individual's residence 30 m from the center of the highway. The dose to the maximum individual is 1.6×10^{-7} rem per shipment. Doses received by the maximum individual, the population, and the transport work force are given in Table 7.4.2-2.

Ecological Effects. Some gases and particulates will be released to the atmosphere from combustion of fossil fuels during normal trucking operations; however, these releases are not expected to be of ecological significance.

TABLE 7.4.2-2. Direct Radiation Doses Received from Truck Transport of Plutonium Oxide

Group	Year 2000	Peak Year 2010	Total Through Year 2050
Maximum individual,[a] rem/yr	3.5×10^{-5}	4.5×10^{-5}	1.8×10^{-3}
Population,[b] man-rem/yr	1.3	1.7	6.6×10^{1}
Transport work force,[c] man-rem	5.3×10^{1}	6.7×10^{1}	2.6×10^{3}

a. Assuming that each shipment passes the same individual.
b. The annual dose to the population from naturally occurring sources along the transport route would be 9.6×10^3 man-rem.
c. It is assumed that two individuals are assigned per truck to alternate driving and resting.

7.4.2.3 Environmental Effects Related to Postulated Accidents

In addition to the use of an overpack, shipments of plutonium oxide would be subject to the packaging requirement of Chapter 10, Code of Federal Regulations, Part 71.42, which specifies that the inner pressure vessel must not release plutonium when the entire package is subjected to the accident test conditions of 10 CFR 71, Appendix B. Plutonium shipments will therefore presumably not be subjected to the accident environment experienced by other radioactive waste shipments that move in routine commerce. No accidental release of radioactive material is postulated for shipments of plutonium oxide.

Injuries and fatalities associated with nonradiological accidents were calculated using an injury rate of 0.44 per million kilometers traveled and a fatality rate of 0.045 per million kilometers traveled. Over the 70-year period ending in 2050 about 53 million kilometers will have been traveled during transport of plutonium oxide. About 23 injuries and about 2 fatalities would be expected from this travel.

Ecological Effects. No accidents or unusual events have been identified that would result in significant effects to terrestrial or aquatic ecosystems.

REFERENCES FOR SECTION 7.4.2

1. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

7.5 COMBINED ENVIRONMENTAL EFFECTS OF REFERENCE TRANSPORTATION MODES

7.5 COMBINED ENVIRONMENTAL EFFECTS OF REFERENCE TRANSPORTATION MODES

In the reference fuel reprocessing mode, solidified high-level waste, fuel residues, and non-high-level transuranic (TRU) wastes will be shipped to a Federal waste repository. Solidified high-level waste and fuel residues will be shipped by rail and non-high-level TRU wastes by truck. The reference treatment for non-high-level TRU wastes is incineration followed by cementation of residues and other wet wastes and particulate solids. The total environmental effects for the year 2000, the peak years (2010 to 2025), and the accumulated effects through the year 2050 are given in Tables 7.5.1-1 through 7.5.1-3 respectively.

TABLE 7.5.1-1. Environmental Effects of Shipping Fuel Reprocessing Wastes in the Year 2000

	Solidified High-Level Waste (rail)	Fuel Residues (rail)	Non-High-Level Transuranic Wastes (truck)	Total
Resource Commitments				
Cask construction, MT				
Stainless steel (SS)	3.5×10^2	7.9×10^2	4.4×10^2	1.6×10^3
Chromium (in SS)	6.3×10^1	1.3×10^2	8.2×10^1	2.8×10^2
Nickel (in SS)	2.8×10^1	6.0×10^1	3.8×10^1	1.3×10^2
Lead, MT	1.0×10^3	2.2×10^3		3.2×10^3
Diesel fuel, m^3/yr	1.9×10^3	3.7×10^3	2.1×10^4	2.7×10^4
Pollutants Released, MT/yr				
Particulates	7.1	2.1×10^1	4.6×10^1	7.4×10^1
Sulfur oxides	1.4×10^1	4.3×10^1	9.7×10^1	1.5×10^2
Carbon oxides	3.4×10^1	1.0×10^2	8.1×10^2	8.5×10^2
Hydrocarbons	2.3×10^1	6.9×10^1	1.4×10^2	2.3×10^2
Nitrogen oxides	8.9×10^1	2.7×10^2	1.4×10^3	1.8×10^3
Aldehydes	1.3	4.0		5.3
Organic acids	1.7	5.2		6.9
Annual Doses from Direct Radiation				
Maximum individual, rem/yr	1.2×10^{-4}	3.6×10^{-4}	6.7×10^{-4}	1.2×10^{-3}
Population,[a] man-rem	1.8	5.4	1.1×10^1	1.8×10^1
Transport workers, man-rem	2.4	7.2	1.0×10^3	1.0×10^3

a. Dose to population from naturally occurring sources, 9.6×10^3 man-rem/yr.

TABLE 7.5.1-2. Environmental Effects of Shipping Fuel Reprocessing Wastes During Peak Years, 2010 to 2025

	Solidified High-Level Waste (rail)	Fuel Residues (rail)	Non-High-Level Transuranic Wastes (truck)	Total
Resource Commitments				
Cask construction, MT				
Stainless steel (SS)	7.2×10^2	9.9×10^2	5.4×10^2	2.3×10^3
Chromium (in SS)	1.3×10^2	1.8×10^2	1.0×10^2	4.1×10^2
Nickel (in SS)	5.8×10^1	8.0×10^1	4.6×10^1	1.8×10^2
Lead, MT	2.2×10^3	3.0×10^3		5.2×10^3
Diesel fuel, m^3/yr	2.9×10^3	4.2×10^3	2.4×10^4	3.1×10^4
Pollutants Released, MT/yr				
Particulates	1.1×10^1	2.4×10^1	5.3×10^1	8.8×10^1
Sulfur oxides	2.2×10^1	4.8×10^1	1.1×10^2	1.8×10^2
Carbon oxides	5.2×10^1	1.1×10^2	9.2×10^2	1.1×10^3
Hydrocarbons	3.6×10^1	7.8×10^1	1.6×10^2	2.7×10^2
Nitrogen oxides	1.4×10^2	3.0×10^2	1.6×10^3	2.0×10^3
Aldehydes	2.1	4.5		6.6
Organic acids	2.7	5.8		8.5
Annual Doses from Direct Radiation				
Maximum individual, rem	2.5×10^{-4}	4.0×10^{-4}	7.7×10^{-4}	1.4×10^{-3}
Population,[a] man-rem	2.8	6.1	1.3×10^1	2.2×10^1
Transport workers, man-rem	3.7	1.8	1.2×10^3	1.2×10^3

a. Dose to population from naturally occurring sources, 9.6×10^3 man-rem/yr.

TABLE 7.5.1-3. Environmental Effects of Shipping Fuel Reprocessing Wastes Through the Year 2050

	Solidified High-Level Waste (rail)	Fuel Residues (rail)	Non-High-Level Transuranic Wastes (truck)	Total
Resource Commitments				
Cask construction, MT				
Stainless steel (SS)	7.2×10^2	9.9×10^2	5.4×10^2	2.3×10^3
Chromium (in SS)	1.3×10^2	1.8×10^2	1.0×10^2	4.1×10^2
Nickel (in SS)	5.8×10^1	8.0×10^1	4.6×10^1	1.8×10^2
Lead, MT	2.2×10^3	3.0×10^3		5.2×10^3
Diesel fuel, m^3/yr	1.4×10^5	1.9×10^5	9.8×10^5	1.3×10^6
Pollutants Released, MT/yr				
Particulates	5.3×10^2	1.1×10^3	2.2×10^3	3.8×10^3
Sulfur oxides	1.1×10^3	2.2×10^3	4.6×10^3	7.9×10^3
Carbon oxides	2.5×10^3	5.0×10^3	3.8×10^4	4.6×10^4
Hydrocarbons	1.7×10^3	3.4×10^3	6.5×10^3	1.2×10^4
Nitrogen oxides	6.6×10^3	1.3×10^4	6.5×10^4	8.5×10^4
Aldehydes	9.9×10^1	2.0×10^2		3.0×10^2
Organic acids	1.3×10^2	2.6×10^2		3.9×10^2
Annual Doses from Direct Radiation				
Maximum individual, rem	1.0×10^{-2}	1.8×10^{-2}	3.2×10^{-2}	6.0×10^{-2}
Population,[a] man-rem	1.3×10^2	2.7×10^2	5.3×10^2	9.3×10^2
Transport workers, man-rem	1.8×10^2	3.6×10^2	4.8×10^4	4.8×10^4
Nonradiological Accidents				
Injuries	2.6×10^1	5.2×10^1	4.2×10^2	5.0×10^2
Fatalities	3	6	4.3×10^1	5.2×10^1

a. Dose to population from naturally occurring sources same period, 6.7×10^5 man-rem.

7.6 ENVIRONMENTAL EFFECTS RELATED TO DECOMMISSIONING OF EQUIPMENT

7.6 ENVIRONMENTAL EFFECTS RELATED TO DECOMMISSIONING OF EQUIPMENT

At this writing no plans have been released for decommissioning equipment to be used in transport of fuel reprocessing wastes. It is reasonable to assume, however, that whenever casks become obsolete either by design, regulation, or damage that important metals such as chromium and nickel will be recycled or placed in storage until recovery becomes cost effective. Some cask components could in some instances become contaminated in such a fashion that decontamination for general use would not be possible. In such cases these parts would, if sufficiently contaminated with transuranium elements, qualify for disposal in a geologic waste repository. The equipment would most likely be handled as failed equipment, the environmental effects of which are covered in Section 5.2.5 of this report. There appear to be no unique properties of failed casks that would require additional treatment or disposal methods.

7.7 SUMMARY OF ADVERSE ENVIRONMENTAL EFFECTS RELATED TO TRANSPORT OF FUEL REPROCESSING WASTES

7.7 SUMMARY OF ADVERSE ENVIRONMENTAL EFFECTS RELATED TO TRANSPORT OF FUEL REPROCESSING WASTES

Environmental effects for the reference modes of waste treatment and transportation are summarized in Section 7.5. The summary presented here is based on the total effects over the 70-year period ending in 2050. The adverse environmental effects of note are 50 traffic fatalities, exposure of the transport work force to about 50,000 man-rem of radiation, and the consumption of about 1.3 million m^3 of diesel fuel.

All three impacts could be reduced (without improved traffic safety) by reducing the distance the waste is shipped or more markedly by replacing truck transport with rail transport. Truck transport accounts for about 80% of the traffic fatalities, essentially all of the dose to the transport worker, and about 78% of the diesel fuel consumed.

Although undesirable, the release of pollutants from transport is not adverse in a practical sense. About 85,000 MT of nitrogen oxides will be released during the 70-year period, which compares with the 61,000 MT released during transport of spent fuel from reactors to repositories. For perspective, one 1000-MWe coal-fired plant will release on the order of 1,700,000 MT of nitrogen oxides over the same period.

Although dose to the population is often included as an adverse impact, the calculated dose of 9.2×10^2 man-rem over 70 years is hardly significant when contrasted with the nominal dose of about 7×10^5 rem received from naturally occurring sources for the same period.

8.0 ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT ASSOCIATED WITH LWR FUEL REPROCESSING - RETRIEVABLE WASTE STORAGE FACILITY

8. ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT ASSOCIATED WITH LWR FUEL REPROCESSING — RETRIEVABLE WASTE STORAGE FACILITY

The reference retrievable waste storage facility (RWSF) is designed to receive and store on an interim basis solidified high-level waste, fuel residues, and non-high-level transuranic wastes from fuel reprocessing plants in either the uranium-only recycle option or the uranium and plutonium recycle option. Transuranic wastes from mixed-oxide fuel fabrication plants may also be sent to the RWSF if the uranium and plutonium recycle option is chosen. The period of storage depends principally on the availability of deep geologic waste isolation facilities. Thus, the reference RWSF is a contingency plan for management of radioactive wastes from fuel reprocessing plants in the event that geologic waste repositories are not available. Although the reference storage period is on the order of 10 to 20 years, the RWSF could apparently be successfully operated for on the order of 100 years.

The reference RWSF is independently located with respect to other postfission production or waste management facilities; it will occupy about 800 ha in the reference environment. Structures for the waste management facilities will occupy about 210 ha as illustrated in Figure 8.1.1-1.

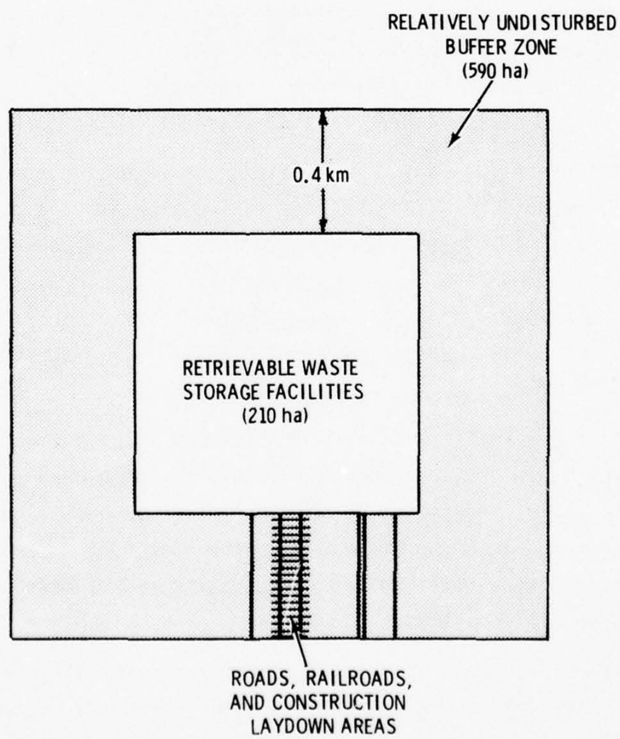

FIGURE 8.1.1-1. Location of the Independent Retrievable Waste Storage Facilities

A separate RWSF (not colocated) is designed to receive and store plutonium oxide in the event that the option of uranium-only recycle with plutonium oxide stored is chosen. Since engineering details of isolating plutonium oxide in deep geologic media have not been worked out, this storage would be needed regardless of the availability of deep geologic waste repositories for other wastes.

This section addresses several alternative methods of interim storage of radioactive wastes at an RWSF and evaluates their environmental effects.

8.1 INTERIM RETRIEVABLE STORAGE OF SOLIDIFIED HIGH-LEVEL WASTE (DOE/ET-0028 Sec. 5.4)[1]

According to present regulations high-level liquid waste must be solidified within 5 years after production. In the reference fuel reprocessing system, high-level liquid waste will be solidified promptly after production; after cooling for at least 6-1/2 years, it will be ready for shipment from the fuel reprocessing plant (FRP) to a waste repository. Interim storage of solidified high-level waste at an RWSF is a contingency option in the event that a deep geologic waste repository is not available to receive high-level waste.

8.1.1 Sealed Storage Cask Facility for Interim Storage of Solidified High-Level Waste (DOE/ET-0028 Sec. 5.4.2)[1]

The sealed storage cask concept for contingency interim storage of solidified high-level waste involves placing the waste container in a high-integrity metal overpack that is contained in a reinforced concrete radiation shield. Air circulating by natural convection between the shield and overpack (sealed cask) removes heat generated from the SHLW.

Three options have been studied for the sealed storage cask concept – the shielded, thick wall, and unshielded alternatives. The shielded sealed storage cask option was selected as the reference storage facility for solidified high-level waste because of its relative economy and added radiation protection. This concept is not currently in use; however, it is based on existing technology and is undergoing full-scale testing at the Hanford nuclear complex with electrically heated dummy waste packages. Figure 8.1.1-2 is a diagram of the reference sealed storage cask.

In the reference case, canisters of SHLW are shipped in casks to the storage facility by truck or railroad. The canisters are removed from the shipping casks, placed in carbon steel overpacks, closed with a lid, and sealed by welding. The overpacked canisters are placed in a radiation shield and moved into the storage yard for placement on a base. The facility provides capabilities for canister retrieval for repackaging and/or offsite shipment and for treating secondary radioactive wastes.

The reference sealed storage cask facility can receive and store 20,000 canisters. The receiving and assembly facilities can accommodate canisters up to 60 cm in diameter and up to 4.6 m long. The initial storage area will hold 2000 canisters and provides for incremental expansion of the storage area up to a total of 20,000 canisters. The storage units and storage area are based on receiving and storing 20,000 canisters that are 30 cm in diameter by 3.0 m long. The waste heat generation per canister is the equivalent of reference fuel 6.5 years out-of-reactor so that each canister generates about 4.4 kJ/s (4.4 kW) of heat.

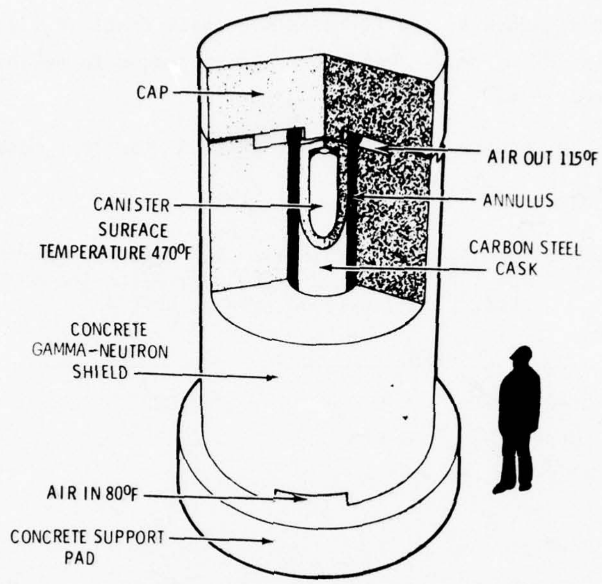

FIGURE 8.1.1-2. Sealed Storage Cask for Interim Storage of Solidified High-Level Waste

It is assumed that SHLW will be shipped to the RWSF for 10 years. Thereafter, it is assumed that shipments to the RWSF will cease and all SHLW will be shipped to the deep geologic waste repository.

REFERENCES FOR SECTION 8.1.1

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

8.1.2 Environmental Effects Related to Facility Construction

Site preparation and reference facility construction may have some effects on the environment and natural resources at the facility site and surrounding area. The information to follow is provided to form a basis for estimating the environmental significance of these activities.

8.1.2.1 Resource Commitments

Construction of the solidified high-level waste sealed storage cask facility will extend over several years. The initial area for storage of 2000 units will occupy approximately 32 ha with an additional 8 ha cleared for construction storage, work yards, temporary buildings, and labor parking. Subsequently, through the year 2000, additional modules of 2000 storage units each will be added until a total capacity of 20,000 storage units is reached. The facility structures ultimately will cover about 120 ha located in an area of 800 ha.

Water use during the initial construction period of 2.5 years will be about 2×10^4 m^3 or approximately 22 m^3/day. This water will be supplied from the R River, described in the

reference environment in Appendix A, and represents a small fraction (less than 0.001%) of the average river flow of 1×10^7 m^3/day. This water use is judged to be insignificant with respect to other downstream uses.

Materials that will be required for the first phase of facility construction (2000 storage units) are listed in Table 8.1.2-1.

TABLE 8.1.2-1. Utilities and Materials Required for Construction of the Solidified High-Level Waste Sealed Storage Cask Facility (2000 storage units)

Resource	Use
Steel, MT	3,000
Copper, MT	27
Aluminum, MT	18
Lumber, m^3	470
Concrete, m^3	13,000
Propane, m^3	265
Diesel fuel, m^3	2,650
Gasoline, m^3	1,900
Electricity	
Peak demand, kW	830
Total consumption, kWh	1,300,000
Manpower, man-yr	1,200

Approximately 1.6 km of new road will be required to provide automobile and truck access from the nearest U.S. highway to the construction site. About 3.2 km of new railroad spur line will also be needed for railroad service to the site.

8.1.2.2 Physical and Chemical Effects

During construction, dust will be generated during grading, blasting, and excavation. Nitrogen oxides, carbon monoxide, and hydrocarbons will be released to the atmosphere by traffic and construction equipment. Concentrations of air pollutants and fuel combustion products at the site boundary will be within applicable Federal air quality standards. In addition, to reduce the effects of dust on the surrounding area, excavation sites and temporary roads can be wetted, oiled, or paved, and construction traffic restricted to roadways whenever possible.

Noise from construction activities will vary with day-to-day schedules, variations in equipment operations, weather conditions, and other factors. The noisiest phase of construction will be during the first 3 or 4 months of construction. Estimated noise level from construction activities is 60 dBA (referenced to 20 μPa) at the property line. Peak sound pressure level from blasting of rock will be 98 dB at the property line and 110 dB at the project exclusion fence. The approximate human response to blasting noise is given in Table 8.1.2-2. Noise levels will be monitored to ensure conformance with Occupational Safety and Health Act, Environmental Protection Agency, state, and local regulations.

TABLE 8.1.2-2. Approximate Human Response to the Effects of Blasting Noise

Peak Blast Sound Pressure Level (60 dBA referenced to 20 μPa)	Response
110 to 120	Little annoyance, no complaints
120 to 130	Moderate annoyance, some complaints
130 to 140	Severe annoyance, moderate number of complaints
140	Many complaints, may break windows, may exceed Occupational Safety and Health Act limit for impulsive noise

Some wind and water erosion may take place in the disturbed areas. Runoff carrying suspended soil particles can be controlled by drainage ditches and contouring of the land. These control measures and the generally level terrain at the site will limit the introduction of silts from the construction area to nearby surface waters.

8.1.2.3 Ecological Effects

The area occupied by the facility structures, 120 ha, will be lost as wildlife habitat during the life of the facility. Noise, dust, and human activity may also displace birds and mammals from adjacent land. Although the construction period will be prolonged, extending through the year 2000, no serious regional impact on the plants and animal communities is expected.

Water withdrawn from the R River during facility construction represents a small fraction of the river flow and should not produce a measurable impact on the river ecosystem. Water intake structures will be properly screened to limit the entrainment of aquatic organisms in the construction water.

8.1.3 Environmental Effects Related to Facility Operation

Some of the factors relating to facility operation may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

8.1.3.1 Resource Commitments

Resources required during planned operation of the solidified high-level waste sealed storage cask facility are given in Table 8.1.3-1.

TABLE 8.1.3-1. Utilities and Materials Required for Operating the Solidified High-Level Waste Sealed Storage Cask Facility

Resource	Average Annual Use
Electricity, kWh	3.2×10^7
Water, m^3	3×10^2
Oil (fuel), m^3	6.6×10^2
Carbon steel, MT	
Casks	1.2×10^3
Storage pads	5.0×10^2
Shields	1.9×10^3
Manpower, man-yr	6.8×10^1

8.1.3.2 Process Effluents

The kinds and quantities of radioactive materials that will be released to the biosphere by the facility are given in Table 8.1.3-2. The radionuclides listed are those that are routinely released to the environment in the ventilation exhaust air and are derived from contaminated shipping casks, decontamination operations, and other plant operations. Radionuclides that will contribute at least 1% of the total dose to a given organ from any pathway to man or that are otherwise of interest are included.

TABLE 8.1.3-2. Radionuclides Released to the Biosphere from the Ventilation System of the Solidified High-Level Waste Sealed Storage Cask Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2	U and Pu Recycle
^{90}Sr	1.3×10^{-7}	1.3×10^{-7}	1.2×10^{-7}
^{95}Nb	1.5×10^{-8}	1.5×10^{-8}	1.5×10^{-8}
^{106}Ru	3.4×10^{-7}	3.4×10^{-7}	3.8×10^{-7}
^{125m}Te	4.4×10^{-9}	4.4×10^{-9}	4.8×10^{-9}
^{127m}Te	8.5×10^{-10}	8.5×10^{-10}	8.5×10^{-9}
^{134}Cs	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}
^{137}Cs	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}
^{144}Ce	5.0×10^{-7}	5.0×10^{-7}	4.8×10^{-7}
^{154}Eu	1.1×10^{-8}	1.1×10^{-8}	1.2×10^{-8}
^{238}Pu	6.0×10^{-9}	3.1×10^{-11}	--
^{239}Pu	6.0×10^{-10}	2.9×10^{-12}	3.6×10^{-12}
^{240}Pu	9.0×10^{-10}	--	--
^{241}Pu	2.2×10^{-7}	--	--
^{241}Am	7.5×10^{-10}	7.5×10^{-10}	1.6×10^{-9}
^{242}Cm	7.0×10^{-9}	7.0×10^{-9}	2.0×10^{-8}
^{244}Cm	2.4×10^{-9}	2.4×10^{-9}	1.5×10^{-8}

There will be no planned releases of radioactive liquid effluents to the biosphere. No liquid effluents will be released from the evaporation pond to the land or surface waters.

Storage of up to 20,000 canisters of solidified high-level waste could produce up to 80 MJ/s of heat that will have to be transferred to the biosphere over an area of about 120 ha. The method of transfer will be by convection within the local atmospheric boundary layer.

8.1.3.3 Physical, Chemical, and Thermal Effects

Heat will be the major environmental pollutant released by the sealed cask storage facility. Considering the rejected heat as a passive pollutant, the ambient temperature change at the fenceline of the facility can be computed. Neuman,[1] in studying industrial pollutants, states that a point source having a source strength of the entire area source can be used to estimate the temperatures downwind of an area source. This procedure is generally applied to large downwind distances from an area source. However, at intermediate distances the point source approach will produce a conservative estimate (an estimate not likely to be exceeded) of temperatures at the receptors. Using this point source approach and a Gaussian diffusion model,[2] downwind temperature changes, as shown in Table 8.1.3-3, were obtained.

TABLE 8.1.3-3. Temperature Change Downwind from the Solidified High-Level Waste Sealed Storage Cask Facility

Distance Downwind, km	Temperature Change, $\Delta t°C$
1	2.1
1.6	0.9
2	0.6
3	0.3
5	0.2
10	0.1

Based on the Neuman method, estimates of the temperature change expected at the facility fenceline (1.6 km) would be about 1°C at full heat load. At distances of 2 to 3 km, the temperature increase is less than 0.6°C, while at 5 km, the increase is about 0.2°C.

In addition, a numerical model developed by Atwater[3] was used to estimate the temperature changes caused by heat released from a sealed cask storage facility. Input parameters included initial surface temperature and air temperature at a height of about 1 m for various upwind and downwind distances. A typical summertime condition was assumed as an initial condition for the numerical simulation. After 6 hr of simulation to allow for equilibrium, the surface temperature with natural conditions and surface temperature with heat source were computed; the temperature change at a downwind distance of 1.6 km was found to be between 0.2 and 0.4°C. Values of temperature change estimated by this method were about half those obtained by using a simple Gaussian diffusion model and suggest that results obtained by the Gaussian approach are not likely to be exceeded in practice.

To provide perspective, the thermal effects from the storage facility are compared with maximum temperature change for a typical urban city and shopping center. Based on data summarized by Oke,[4] a temperature change of 2°C would correspond to a thermal structure around a town of 1000 people. Norwind[5] based measured data around a suburban shopping center of 80 ha and determined that the maximum temperature above ambient was also on the order of 2 to 2.5°C. These comparisons suggest that release of heat is not a significant environmental impact at a sealed storage cask facility.

Since no other nonradioactive materials will be released, no environmental impacts are expected from normal facility operation.

8.1.3.4 Radiological Effects

Calculated radiation doses to individuals in the vicinity of the solidified high-level waste sealed storage cask facility are based on the radionuclide releases listed in Table 8.1.3-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). The only exposure pathway to man from the facility is via airborne contaminants; there are no planned releases of radioactive materials to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 8.1.3-4. For comparison, the dose to an individual from naturally occurring sources is about 0.1 rem/yr.

TABLE 8.1.3-4. Annual Dose to the Maximum Individual from Gaseous Effluents Released by the Solidified High-Level Waste Sealed Storage Cask Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}
Inhalation	1.3×10^{-11}		3.6×10^{-13}	1.1×10^{-9}	1.7×10^{-10}
Ingestion	1.4×10^{-12}	0	1.2×10^{-16}	6.5×10^{-14}	3.7×10^{-12}
Total	1.4×10^{-11}	6.5×10^{-14}	4.3×10^{-13}	1.1×10^{-9}	1.7×10^{-10}
		U Recycle, Pu Stored as PuO_2			
Air submersion	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}
Inhalation	8.5×10^{-12}		3.6×10^{-13}	8.5×10^{-10}	6.5×10^{-11}
Ingestion	1.4×10^{-12}	0	1.2×10^{-16}	6.5×10^{-14}	3.7×10^{-12}
Total	9.9×10^{-12}	6.5×10^{-14}	4.3×10^{-13}	8.5×10^{-10}	6.9×10^{-11}
		U and Pu Recycle			
Air submersion	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}	6.5×10^{-14}
Inhalation	1.4×10^{-11}		3.9×10^{-13}	1.4×10^{-9}	1.5×10^{-10}
Ingestion	1.3×10^{-12}	0	1.3×10^{-16}	6.5×10^{-14}	3.4×10^{-12}
Total	1.5×10^{-11}	6.5×10^{-14}	3.9×10^{-13}	1.4×10^{-9}	1.5×10^{-10}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.

b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the facility was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 8.1.3-5 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 5.5×10^{-7} man-rem received from process sources as given in Table 8.1.3-5.

TABLE 8.1.3-5. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Solidified High-Level Waste Sealed Storage Cask Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	2.2×10^{-9}	2.2×10^{-9}	2.2×10^{-9}	2.2×10^{-9}
Inhalation	4.2×10^{-7}	1.2×10^{-8}	3.6×10^{-5}	5.5×10^{-5}
Ingestion	1.3×10^{-7}	1.3×10^{-11}	7.0×10^{-9}	3.3×10^{-7}
Total	5.5×10^{-7}	1.4×10^{-8}	3.6×10^{-5}	5.5×10^{-5}
	U Recycle, Pu Stored as PuO_2			
Air submersion	2.2×10^{-9}	2.2×10^{-9}	2.2×10^{-9}	2.2×10^{-9}
Inhalation	2.8×10^{-7}	1.2×10^{-8}	2.9×10^{-5}	2.2×10^{-6}
Ingestion	1.3×10^{-7}	1.3×10^{-11}	7.0×10^{-9}	3.3×10^{-7}
Total	4.1×10^{-7}	1.4×10^{-8}	2.9×10^{-5}	2.5×10^{-6}
	U and Pu Recycle			
Air submersion	2.2×10^{-9}	2.2×10^{-9}	2.2×10^{-9}	2.2×10^{-9}
Inhalation	4.4×10^{-7}	1.3×10^{-8}	4.7×10^{-5}	4.8×10^{-6}
Ingestion	1.3×10^{-7}	1.3×10^{-11}	7.0×10^{-9}	3.1×10^{-7}
Total	5.7×10^{-7}	1.5×10^{-8}	4.7×10^{-5}	5.1×10^{-6}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the solidified high-level waste sealed storage cask facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 120 man-rem. Table 8.1.3-6 summarizes the annual total-body dose to the work force and the general public from process and naturally occurring sources in the year 2000.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 8.1.3-7 and 8.1.3-8 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 8.1.3-9. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with <0.001 man-rem received from the reference facility.

TABLE 8.1.3-6. Summary of Annual Total-Body Doses Received from Operation of the Solidified High-Level Waste Sealed Storage Cask Facility and from Naturally Occurring Sources

	Dose, man-rem
Solidified high-level waste sealed storage cask facility	
Process work force	120
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

TABLE 8.1.3-7. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released by the Solidified High-Level Waste Sealed Storage Cask Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	2.0×10^{-12}	2.0×10^{-12}	2.0×10^{-12}	2.0×10^{-12}
Inhalation	4.7×10^{-9}	1.1×10^{-11}	3.3×10^{-8}	7.5×10^{-8}
Ingestion	8.5×10^{-10}	3.7×10^{-15}	3.5×10^{-12}	3.3×10^{-9}
Total	5.6×10^{-9}	1.3×10^{-11}	3.3×10^{-8}	7.8×10^{-8}
	U Recycle, Pu Stored as PuO_2			
Air submersion	2.0×10^{-12}	2.0×10^{-12}	2.0×10^{-12}	2.0×10^{-12}
Inhalation	2.0×10^{-9}	1.1×10^{-11}	2.0×10^{-8}	1.5×10^{-8}
Ingestion	8.5×10^{-9}	3.7×10^{-15}	3.5×10^{-12}	3.3×10^{-9}
Total	1.1×10^{-8}	1.3×10^{-11}	2.0×10^{-8}	1.8×10^{-8}
	U and Pu Recycle			
Air submersion	2.0×10^{-12}	2.0×10^{-12}	2.0×10^{-12}	2.0×10^{-12}
Inhalation	3.5×10^{-9}	1.2×10^{-11}	4.8×10^{-8}	4.0×10^{-8}
Ingestion	7.5×10^{-10}	3.9×10^{-15}	3.5×10^{-12}	3.1×10^{-10}
Total	4.3×10^{-9}	1.4×10^{-11}	4.8×10^{-8}	4.0×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. On this basis, less than one health effect would be expected from dose received by the population from sealed cask storage of solidified high-level waste.

TABLE 8.1.3-8. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the Solidified High-Level Waste Sealed Storage Cask Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}
Inhalation	1.5×10^{-4}	3.5×10^{-7}	1.1×10^{-3}	2.4×10^{-3}
Ingestion	7.5×10^{-5}	3.9×10^{-10}	3.9×10^{-7}	3.0×10^{-4}
Total	2.3×10^{-4}	4.2×10^{-7}	1.1×10^{-3}	2.7×10^{-3}
	U Recycle, Pu Stored as PuO_2			
Air submersion	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}
Inhalation	6.5×10^{-5}	3.6×10^{-7}	6.5×10^{-4}	4.7×10^{-4}
Ingestion	7.5×10^{-5}	3.9×10^{-10}	3.9×10^{-7}	3.0×10^{-4}
Total	1.4×10^{-4}	4.3×10^{-7}	6.5×10^{-4}	7.7×10^{-4}
	U and Pu Recycle			
Air submersion	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}
Inhalation	1.2×10^{-4}	3.8×10^{-7}	1.6×10^{-3}	1.3×10^{-3}
Ingestion	7.0×10^{-5}	4.1×10^{-10}	3.9×10^{-7}	2.7×10^{-4}
Total	1.9×10^{-4}	4.5×10^{-7}	1.6×10^{-3}	1.6×10^{-3}

TABLE 8.1.3-9. Summary of 70-Year Total-Body Doses Received from Operation of the Solidified High-Level Waste Sealed Storage Cask Facility and from Naturally Occurring Sources

	Dose, man-rem
Solidified high-level waste sealed storage cask facility	
Process work force (30 yr)	3,600
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

8.1.3.5 Ecological Effects

There will be no terrestrial consequences of any significance associated with normal operation of the sealed storage cask facility. During normal operation nonradioactive gaseous effluents will be released only from facility ventilation air. Some local atmospheric heating is expected from the facility. Estimated temperature change at the facility fenceline (1.6 km) is 1°C at full heat load; at distances of 2 to 3 km the temperature rise is <0.6°C; at a distance of 5 km the increase is about 0.2°C. These temperature changes are within the natural temperature range and will not have a measurable environmental effect.

Approximately 3×10^2 m^3 of water per year will be used for plant operation. This will amount to a withdrawal of less than 1% of the minimum flow of the R River and will have no detrimental effects upon the aquatic ecosystem.

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8.1.4 Environmental Effects Related to Postulated Accidents

Only one accident, canister failure in the receiving cell (Accident 5.4.19), has been postulated to release radioactive material from this facility; the accident scenario is given in detail in DOE/ET-0028.[1] The accident, classified as moderate, involves the rupture of a solidified high-level waste canister in the facility receiving cell and the subsequent release of radioactive materials through the high-efficiency particulate air (HEPA) filters. Doses are estimated for two cases: 1) the rupture of a canister containing calcined high-level waste and the environmental release of 0.015 mg of radioactive materials and 2) the rupture of a canister containing waste in borosilicate glass and the release of 0.0019 mg of radioactive material to the environment. Calculated amounts of radionuclides released for the calcination and vitrification cases are given in Tables 8.1.4-1 and 8.1.4-2 respectively. Radionuclides that contribute 1% or more to the organ doses or that are of special interest are listed.

TABLE 8.1.4-1. Radionuclides Released to the Atmosphere from Canister Failure in the Solidified (Calcined) High-Level Waste Sealed Storage Cask Facility Receiving Cell (Ci)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2	U and Pu Recycle
^{90}Sr	1.5×10^{-2}	1.5×10^{-2}	1.4×10^{-2}
^{90}Y	1.5×10^{-2}	1.5×10^{-2}	1.4×10^{-2}
^{125m}Te	6.3×10^{-5}	6.3×10^{-5}	6.9×10^{-5}
^{134}Cs	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
^{137}Cs	2.2×10^{-2}	2.2×10^{-2}	2.2×10^{-2}
^{238}Pu	8.4×10^{-4}		
^{239}Pu	8.4×10^{-5}	4.2×10^{-7}	5.2×10^{-7}
^{241}Pu	2.0×10^{-2}		
^{241}Am	8.0×10^{-4}	4.5×10^{-4}	7.8×10^{-4}
^{244}Cm	2.5×10^{-4}	2.5×10^{-4}	1.5×10^{-3}

TABLE 8.1.4-2. Radionuclides Released to the Atmosphere from Canister Failure in the Solidified (Vitrified) High-Level Waste Sealed Storage Cask Facility Receiving Cell (Ci)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2	U and Pu Recycle
^{90}Sr	5.7×10^{-4}	5.7×10^{-4}	5.3×10^{-4}
^{90}Y	5.7×10^{-4}	5.7×10^{-4}	5.3×10^{-4}
^{125m}Te	2.4×10^{-6}	2.4×10^{-6}	2.6×10^{-6}
^{134}Cs	6.2×10^{-5}	6.2×10^{-5}	6.2×10^{-5}
^{137}Cs	8.2×10^{-4}	8.2×10^{-4}	8.2×10^{-4}
^{238}Pu	3.2×10^{-5}		5.7×10^{-5}
^{239}Pu	3.2×10^{-6}	1.6×10^{-8}	3.9×10^{-6}
^{241}Pu	7.6×10^{-4}		1.3×10^{-3}
^{241}Am	3.0×10^{-5}	1.7×10^{-5}	2.9×10^{-5}
^{244}Cm	9.4×10^{-6}	9.4×10^{-6}	5.6×10^{-5}

The 1-year dose and 70-year dose commitment to the maximum individual are given in Tables 8.1.4-3 and 8.1.4-4, respectively, for calcined waste and in Tables 8.1.4-5 and 8.1.4-6 for vitrified waste.

TABLE 8.1.4-3. One-Year Dose to the Maximum Individual Resulting from a Canister Failure in the Solidified (Calcined) High-Level Waste Sealed Storage Cask Facility Receiving Cell (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	1.3×10^{-6}	5.1×10^{-7}	5.1×10^{-7}	5.1×10^{-7}	5.1×10^{-7}
Inhalation		3.9×10^{-4}	1.5×10^{-6}	2.5×10^{-2}	5.3×10^{-3}
Total	1.3×10^{-6}	3.9×10^{-4}	2.0×10^{-6}	2.5×10^{-2}	5.3×10^{-3}
		U Recycle, Pu Stored as PuO_2			
Air submersion	1.3×10^{-6}	5.6×10^{-7}	5.6×10^{-7}	5.6×10^{-7}	5.6×10^{-7}
Inhalation		2.1×10^{-4}	1.5×10^{-6}	9.8×10^{-3}	1.3×10^{-3}
Total	1.3×10^{-6}	2.1×10^{-4}	2.1×10^{-6}	9.8×10^{-3}	1.3×10^{-3}
		U and Pu Recycle			
Air submersion	1.3×10^{-6}	5.7×10^{-7}	5.7×10^{-7}	5.7×10^{-7}	5.7×10^{-7}
Inhalation		3.3×10^{-4}	1.7×10^{-6}	2.7×10^{-2}	3.2×10^{-3}
Total	1.3×10^{-6}	3.3×10^{-4}	2.3×10^{-6}	2.7×10^{-2}	3.2×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

TABLE 8.1.4-4. 70-Year Dose Commitment to the Maximum Individual Resulting from a Canister Failure in the Solidified (Calcined) High-Level Waste Sealed Storage Cask Facility Receiving Cell (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	1.3×10^{-6}	5.6×10^{-7}	5.6×10^{-7}	5.6×10^{-7}	5.6×10^{-7}
Inhalation		1.1×10^{-2}	1.5×10^{-6}	6.1×10^{-2}	1.7×10^{-1}
Total	1.3×10^{-6}	1.1×10^{-2}	2.1×10^{-6}	6.1×10^{-2}	1.7×10^{-1}
		U Recycle, Pu Stored as PuO_2			
Air submersion	1.3×10^{-6}	5.6×10^{-7}	5.6×10^{-7}	5.6×10^{-7}	5.6×10^{-7}
Inhalation		4.4×10^{-3}	1.5×10^{-6}	2.3×10^{-2}	4.0×10^{-2}
Total	1.3×10^{-6}	4.4×10^{-3}	2.1×10^{-6}	2.3×10^{-2}	4.0×10^{-2}
		U and Pu Recycle			
Air submersion	1.3×10^{-6}	5.7×10^{-7}	5.7×10^{-7}	5.7×10^{-7}	5.7×10^{-7}
Inhalation		7.7×10^{-3}	1.7×10^{-6}	6.5×10^{-2}	9.2×10^{-2}
Total	1.3×10^{-6}	7.7×10^{-3}	2.3×10^{-6}	6.5×10^{-2}	9.2×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

TABLE 8.1.4-5. One-Year Dose Commitment to the Maximum Individual Resulting from a Canister Failure in the Solidified (Vitrified) High-Level Waste Sealed Storage Cask Facility Receiving Cell (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	5.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation		1.5×10^{-5}	5.8×10^{-8}	9.6×10^{-4}	2.0×10^{-4}
Total	5.1×10^{-8}	1.5×10^{-5}	7.9×10^{-8}	9.6×10^{-4}	2.0×10^{-4}
		U Recycle, Pu Stored as PuO_2			
Air submersion	5.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation		7.9×10^{-6}	5.8×10^{-8}	3.7×10^{-4}	5.0×10^{-5}
Total	5.1×10^{-8}	7.9×10^{-6}	7.9×10^{-8}	3.7×10^{-4}	5.0×10^{-5}
		U and Pu Recycle			
Air submersion	5.0×10^{-8}	2.2×10^{-8}	2.2×10^{-8}	2.2×10^{-8}	2.2×10^{-8}
Inhalation		2.3×10^{-5}	6.4×10^{-8}	1.8×10^{-3}	3.5×10^{-4}
Total	5.0×10^{-8}	2.3×10^{-5}	8.6×10^{-8}	1.8×10^{-3}	3.5×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

TABLE 8.1.4-6. 70-Year Dose Commitment to the Maximum Individual Resulting from a Canister Failure in the Solidified (Vitrified) High-Level Waste Sealed Storage Cask Facility Receiving Cell (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	5.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation		4.1×10^{-4}	5.8×10^{-8}	2.3×10^{-3}	6.4×10^{-3}
Total	5.1×10^{-8}	4.1×10^{-4}	7.9×10^{-8}	2.3×10^{-3}	6.4×10^{-3}
		U Recycle, Pu Stored as PuO_2			
Air submersion	5.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation		1.7×10^{-4}	5.8×10^{-8}	8.9×10^{-4}	1.5×10^{-3}
Total	5.1×10^{-8}	1.7×10^{-4}	7.9×10^{-8}	8.9×10^{-4}	1.5×10^{-3}
		U and Pu Recycle			
Air submersion	5.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation		6.3×10^{-4}	6.4×10^{-8}	4.3×10^{-3}	1.1×10^{-2}
Total	5.1×10^{-8}	6.3×10^{-4}	8.5×10^{-8}	4.3×10^{-3}	1.1×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

Doses amounting to small fractions of a rem received as a result of postulated accidents are not considered significant.

REFERENCES FOR SECTION 8.1.4

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

8.2 INTERIM RETRIEVABLE STORAGE OF PACKAGED FUEL RESIDUES

(DOE/ET-0028 Section 5.2)

8.2 INTERIM RETRIEVABLE STORAGE OF PACKAGED FUEL RESIDUES (DOE/ET-0028 Sec. 5.2)

In the event that it is necessary to await availability of a final repository, facilities will be required for interim storage of canisters of fuel residues and failed equipment. Two interim storage alternatives are considered: vault storage and near-surface storage.

8.2.1 Vault Storage of Fuel Residues (DOE/ET-0028 Sec. 5.2.1)

In vault storage, the fuel residues are contained in sealed (welded) cylindrical stainless steel canisters and stored in partially buried reinforced concrete cells arranged in modular fashion. This storage method provides for secondary containment in the event of canister leaks; simple placement and retrieval of canisters in and from the storage cells; canister cooling by air circulation; and shielding from penetrating radiation.

The two cases for storage at a site located independently of the FRP include capacity to store a 5% excess of canisters generated by all reference FRPs through the year 1990 (case A, 6200 canisters) and through the year 1995 (case B, 11,900 canisters).

Figure 8.2-1 shows a plot plan of the fuel residue vault storage facility. The floor slab of each storage compartment slopes toward a longitudinal floor drain that ends in a sump. Here any liquid from the vault is monitored before release to a retention pond.* Each storage space consists of a galvanized steel pipe sleeve with a plate welded to the bottom and suspended from the roof slab.

Several screened air intake structures are provided on each side of the vault to permit ambient air to enter the storage cell and circulate around the canisters. Hot air will leave the cell through vents located at the center of the structure where radiation monitors are placed to detect any release of airborne contamination.

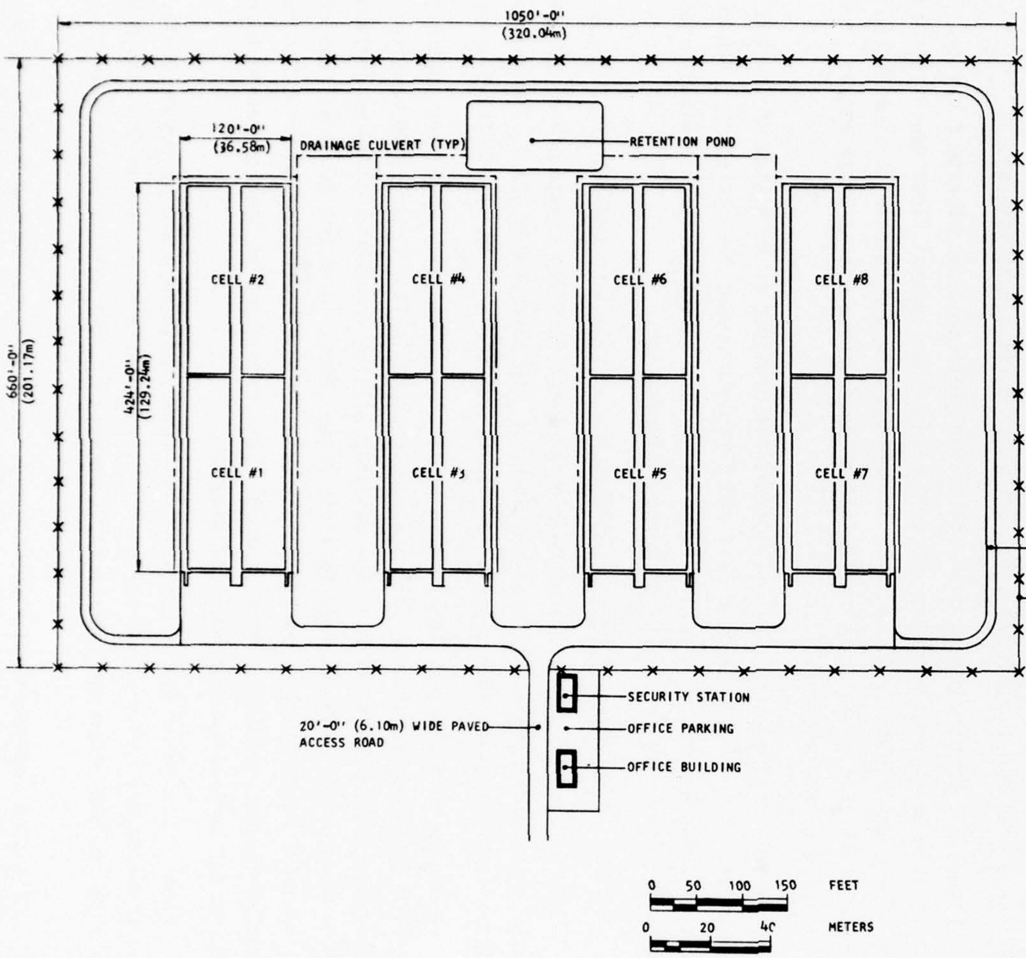
8.2.1.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The interim vault storage facility will have a storage capacity for 6200 canisters for case A (storage requirements in 1990) and 11,900 canisters for case B (storage requirements in 1995). The facility will be located on a 160-ha portion of the 800-ha retrievable waste storage facility site. About 14 ha and 26 ha will be required for case A and B respectively. An additional 2 ha will be needed for construction storage, work yards, buildings, and work force parking. This commitment of land is judged to be acceptable and without serious environmental consequence.

About 1.5×10^5 m^3 and 2.9×10^5 m^3 of water for case A and B, respectively, will be used during the 3-year construction period. This water will be withdrawn from the R River, described in the reference environment (Appendix A), and will represent only a small fraction

* Disposition of contaminated liquids would require collection and treatment, including immobilization. The level of contamination at which such action would be required has not been identified.



NOTES:

1. FOR DETAILS OF ONE TYPICAL CELL SEE FIGURE 5.2.2
2. EIGHT CELLS SHOWN FOR STORAGE OF UN-COMPACTED HULLS.
3. LAND AREA INSIDE FENCE IS 16 ACRES (6.5ha)
4. STORAGE CAPACITY FOR 312 CANISTERS PER CELL OR 2496 TOTAL PROVIDED.

FIGURE 8.2-1. Fuel Residue Vault Storage Facility Plot Plan

of the 3.9 x 10^9 m^3 average annual river flow. This requirement is judged to be insignificant with respect to other downstream water uses. During the construction period wells may also be able to supply the necessary amount of water without environmental consequence.

Approximately 1.6 km of 2-lane paved road will be required between the facility and the nearest U.S. highway.

Commitments of other resources necessary for construction of the interim vault storage facility are given in Table 8.2.1-1.

TABLE 8.2.1-1. Materials and Utilities Required for Construction of the Interim Vault Storage Facility for Fuel Residues

Resource	Use: Case A (1990)	Use: Case B (1995)
Steel, MT	3.6 x 10^4	7.0 x 10^4
Copper, MT	2.2 x 10^1	4.3 x 10^1
Lead, MT	1.1 x 10^2	2.2 x 10^2
Lumber, m^3	7.8 x 10^3	1.5 x 10^4
Concrete, m^3	1.5 x 10^5	2.8 x 10^5
Propane, m^3	1.1 x 10^3	2.2 x 10^3
Diesel fuel, m^3	1.1 x 10^4	2.2 x 10^4
Gasoline, m^3	7.6 x 10^3	1.4 x 10^4
Electricity		
Peak demand, kW	3.1 x 10^3	6.0 x 10^3
Total consumption, kWh	5.7 x 10^6	1.1 x 10^7
Manpower, man-yr	5.0 x 10^3	9.6 x 10^3

Physical and Chemical Effects. Effects on air quality from construction of the vault storage facility will be minor; such effects will be caused by fugitive dust and the atmospheric release of fossil fuel combustion products.

Excavation for up to nineteen 37- x 129-m rectangular vaults to a depth of about 5 m and for a 55- x 110-m retention basin to a depth of about 3 m (case B) is not expected to significantly affect groundwater movement. Construction activities for the facility and access road will affect surface drainage and may cause sediment runoff and temporarily impair the quality of nearby surface water.

Ecological Effects. During the 3-year construction period up to 290,000 m^3 of water will be used; it will be drawn from the R River near the reference site or possibly from wells. This amount of water represents an insignificant fraction ($<0.001\%$) of the 3.9 x 10^9 m^3 average annual river flow. No ecological impacts on the river ecosystem are expected from this volume of water removal.

Energy consumption during construction will include approximately 8000 m^3 of fossil fuels. Although the emissions resulting from burning these fuels may result in occasional locally elevated levels of hydrocarbons and nitrogen oxides, these levels are estimated to be well

below Federal standards. No ecological effects are expected to result from emissions related to construction of the vault storage facility.

8.2.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. The resources required during operation of the vault storage facility for fuel residues are listed in Table 8.2.1-2. The commitment of these quantities of resources is judged to be insignificant in relation to their other uses.

TABLE 8.2.1-2. Materials and Utilities Required for Operation of the Interim Vault Storage Facility for Fuel Residues

Resource	Average Annual Use
Electricity, kWh	1.0×10^7
Diesel fuel, m^3	1.5×10^1
Manpower, man-yr	4

Process Effluents. The burning of about 15 m^3/yr of fossil fuels to operate equipment at the vault storage facility will release small amounts of pollutants to the atmosphere. However, these quantities will be several orders of magnitude below Federal air quality standards. There are no planned releases of radioactive material to air, water, or ground and therefore no pathways for radionuclides to man.

An estimated 110,000 m^3/yr of water for case A and 200,000 m^3/yr of water for case B will result from storm runoff (assuming annual precipitation of 0.76 m). This waste will be diverted to a retention basin to check for radioactive contamination. The capacity assumed for the retention basin (9,300 m^3 for case A and 18,000 m^3 for case B) is adequate to store about one-half of the storm runoff from the maximum potential 24-hr precipitation of 0.13 m ($\sim$34,000 m^3). The method of disposition of this excess storm runoff is not defined, and discussion of the possible environmental effects requires an engineering decision on drainage area or retention pond size.

The amount of heat generated will be about 4.4×10^7 MJ/yr for case A and 8.2×10^7 MJ/yr for case B. This heat will be released directly to the atmosphere through natural convection and conduction through the roof, sides, and bottom of the vault shielding.

Physical, Chemical, and Thermal Effects. The amount of heat generated will be 4.4×10^7 MJ/yr for case A and 8.2×10^7 MJ/yr for case B. This heat will be transferred to the atmosphere by natural convection through a vent in the storage cells and by conduction through the roof, sides, and bottom of the vault shielding. No surface effects will result from the vented release. The heat load rejected to the atmosphere over the entire site will be 0.25 to 0.48% of the urban heat load value for a town of 20,000 to 30,000 population and is not expected to have any important environmental impact.

Radiological Effects. No releases of radioactive material to air, water, or ground are planned during routine operation; therefore, no radiological effects are expected.

Ecological Effects. The burning of approximately 15 m^3/yr of fossil fuel to operate equipment at the vault storage facility will result in minor incremental emissions to the atmosphere. No ecological impact will result from these emissions.

No ecological effects are expected from the release of up to 6.6 x 10^7 MJ/yr of heat to the atmosphere. The estimated downwind rise in air temperature will be less than 0.1°C at a distance of 1 km from the facility.

8.2.1.3 Environmental Effects Related to Postulated Accidents

No minor accidents resulting in the release of radioactive materials to the biosphere were identified for operation of the vault storage facility.

One moderate accident is postulated to release radioactive material. The scenario for this accident is provided in DOE/ET-0028[1] and the accident is listed below.

Accident Number	Description
5.2.1	Waste zirconium hulls canister breached by drop

For this accident it was assumed that a canister containing 1320 kg of zirconium hulls is breached, thus exposing 0.14 of the contained metal to the atmosphere. About 5.4 x 10^{-4} of the exposed material is entrained in the atmosphere. A ground level release period of 1 hr and a 1.5-year storage decay time out of the reactor is assumed. The estimated frequency of this accident is 0.2 per year. The radioactive material associated with such an event is given in Table 8.2.1-3.

Seventy-year dose commitments to the maximum individual were calculated and are presented in Table 8.2.1-4. Numerically, the largest of these dose values (dose to the bone received from the uranium only recycle mode) is less than 1% of the dose the individual would have received from naturally occurring sources during the period and is therefore considered insignificant.

No serious accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

REFERENCES FOR SECTION 8.2.1

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

TABLE 8.2.1-3. Radionuclides Released to the Atmosphere from a Moderate Accident in the Interim Vault Storage Facility for Fuel Residues

Radionuclide	Release, Ci: U Recycle Only	Release, Ci: U and Pu Recycle
^{3}H	2.2×10^{-2}	2.2×10^{-2}
^{14}C	2.1×10^{-5}	2.1×10^{-5}
^{60}Co	3.5×10^{-2}	3.5×10^{-2}
^{90}Sr	1.1×10^{-2}	1.1×10^{-2}
^{95}Zr	2.9×10^{-2}	2.9×10^{-2}
^{106}Ru	3.3×10^{-2}	3.0×10^{-2}
$^{125\underline{m}}Te$	4.2×10^{-4}	3.9×10^{-4}
$^{127\underline{m}}Te$	7.5×10^{-5}	7.3×10^{-5}
^{134}Cs	2.1×10^{-2}	2.1×10^{-2}
^{137}Cs	1.6×10^{-2}	1.6×10^{-2}
^{144}Ce	4.2×10^{-2}	4.4×10^{-2}
^{238}Pu	9.6×10^{-4}	5.4×10^{-4}
^{239}Pu	6.3×10^{-5}	5.1×10^{-5}
^{241}Pu	3.2×10^{-2}	1.9×10^{-2}
^{242}Cm	1.7×10^{-3}	6.1×10^{-4}
^{244}Cm	1.3×10^{-3}	2.1×10^{-4}

TABLE 8.2.1-4. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident in the Interim Vault Storage Facility for Fuel Residues (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle Only			
Air submersion	7.3×10^{-6}	4.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}
Inhalation		8.1×10^{-3}	1.2×10^{-5}	7.4×10^{-2}	1.4×10^{-1}
Total	7.3×10^{-6}	8.1×10^{-3}	1.6×10^{-5}	7.4×10^{-2}	1.4×10^{-1}
		U and Pu Recycle			
Air submersion	4.2×10^{-6}	7.2×10^{-6}	7.2×10^{-6}	7.2×10^{-6}	7.2×10^{-6}
Inhalation		4.7×10^{-3}	1.1×10^{-5}	3.7×10^{-2}	7.3×10^{-2}
Total	4.2×10^{-6}	4.7×10^{-3}	1.8×10^{-5}	3.7×10^{-2}	7.3×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the site center with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.1×10^{-4} sec/m^3.

8.2.2 Subsurface Storage of Fuel Residues (DOE/ET-0028 Sec. 5.2.2)

Subsurface storage of fuel residues is similar to the vault storage concept (Section 8.2.1) except that the facility is an engineered above-grade soil structure (berm). The canisters are placed in caissons positioned vertically in the berm and capped with a steel and concrete plug. The berm and plug provide the required shielding from penetrating radiation. Alternative concepts for subsurface storage involve variations in design and handling. Berm caisson storage was selected as the reference alternative on the basis of 1) ease of canister placement and retrieval with minimum exposure of personnel, 2) secondary containment in the event of canister leaks, 3) isolation of contamination from a failed canister, and 4) adequate dissipation of isotopic heat.

Two cases are considered for the retrievable waste storage facility capacity to store canisters from all reference FRPs: through the year 1990 (case A, 6200 canisters) and through the year 1995 (case B, 11,900 canisters). Handling operations at the subsurface storage facility are identical to those at the vault storage facility.

Figure 8.2.2-1 shows a plot plan of the subsurface storage facility for fuel residues; a section view of a typical berm is provided in Section 5.2.2 of DOE/ET-0028.[1] The required capacity is obtained by constructing multiples of these berms or by increasing the capacity of existing berms. The berm is compacted to 95% of its maximum dry density. Individual storage positions have removable shielding plugs 1.2 m thick to allow for storage and retrieval of containers through a hulls (fuel residue) transfer device. A 60-ton gantry crane, which runs over one-half of the berm, handles the cask, hulls transfer device, and shielding plugs. Cooling of the berms is achieved by heat conduction through the soil to the atmosphere.

8.2.2.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The subsurface storage facility requires an area of 160 ha within the 800-ha retrievable waste storage facility site. The storage facilities will require areas of 24 ha and 47 ha for case A (1990) and case B (1995) respectively. An additional area of about 2 ha will be needed for construction storage, work yards, temporary buildings, and work force parking.

About 3.8×10^4 m^3 and 7.2×10^4 m^3 of water will be required for construction of the case A and case B facilities respectively. This water will be supplied from the R River, which is described in the reference environment (Appendix A), and represents less than 0.002% of the average annual river flow. Removal of this volume of water from the river is judged to be insignificant with respect to other downstream uses. Wells could also supply this amount of water without environmental consequence.

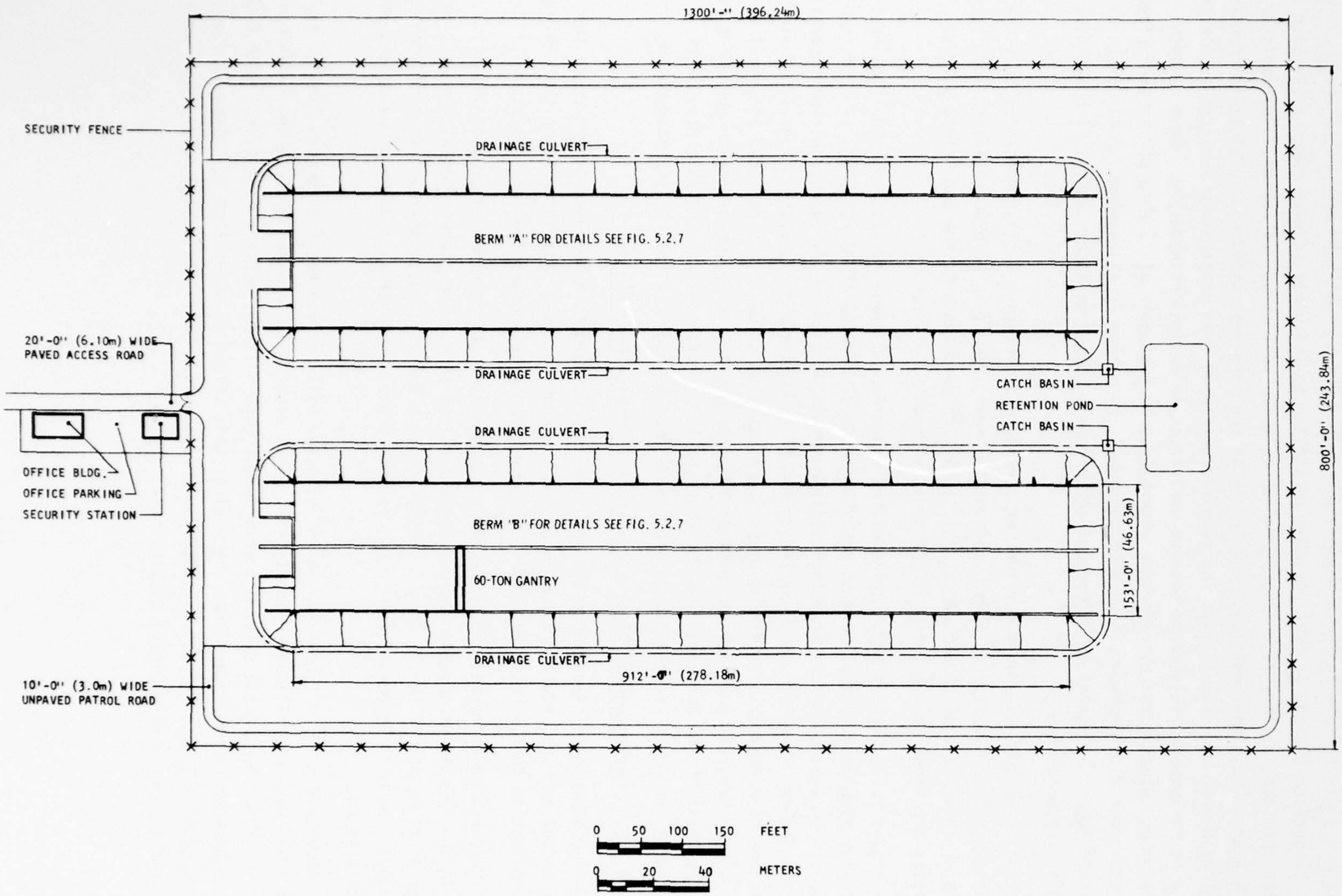


FIGURE 8.2.2-1. Plot Plan of the Subsurface Storage Facility for Fuel Residues

Commitments of other resources during construction of the subsurface storage facility are listed in Table 8.2.2-1.

TABLE 8.2.2-1. Materials and Utilities Required for Construction of the Subsurface Storage Facility for Fuel Residues

Resource	Use Case A (1990)	Use Case B (1995)
Steel, MT	9.0×10^3	1.7×10^4
Copper, MT	1.1×10^1	2.2×10^1
Lead, MT	1.1×10^2	2.2×10^2
Lumber, m^3	2.6×10^3	5.0×10^3
Concrete, m^3	4.2×10^4	8.0×10^4
Propane, m^3	2.9×10^2	5.5×10^2
Diesel fuel, m^3	2.9×10^3	5.5×10^3
Gasoline, m^3	2.0×10^3	3.8×10^3
Electricity		
Peak demand, kW	1.4×10^3	2.7×10^3
Total consumption, kWh	1.5×10^6	2.8×10^6
Manpower, man-yr	1.3×10^3	2.5×10^3

The independent subsurface storage facility will also require the construction of approximately 1.6 km of two-lane paved road to the nearest U.S. highway.

Physical and Chemical Effects. Effects on air quality from construction of the subsurface storage facility will be minor; such effects will be caused by fugitive dust and the atmospheric release of fossil fuel combustion products. The estimated fenceline concentrations of fuel combustion products (hydrocarbons, nitrogen oxides, sulfur oxides, carbon monoxide, particulates) are several orders of magnitude below Federal air quality standards.

Excavation for a 67- x 134-m retention basin to a depth of about 3 m (case B) is not expected to affect groundwater movement. Construction activities for the facility and access road will affect surface drainage and may cause sediment runoff and temporarily impair the quality of nearby surface water.

Ecological Effects. No serious ecological impacts are expected from construction of the subsurface storage facility. Land area requirements are on the order of 160 ha with only 30% or less to be occupied by the facility.

During the 2-year construction period up to 72,000 m^3 of water will be used; it will be drawn from the R River near the reference site. This amount of water represents an insignificant fraction (<0.002%) of the 3.9×10^9 m^3 average annual river flow. No ecological impacts on the river ecosystem are expected from this volume of water removal.

Maximum energy consumption (case B) during construction will include approximately 9400 m^3 of fossil fuels. The emissions resulting from burning these fuels may result in occasional locally elevated levels of hydrocarbons and nitrogen oxides; however, the quantities of emission products will be well below Federal air quality standards. No ecological effects are expected to result from emissions related to construction of the subsurface storage facility.

8.2.2.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. The resources required during operation of the subsurface storage facility are the same as those given in Table 8.2.1-2 (Section 8.2.1).

Process Effluents. There are no planned releases of radioactive material to air, water, or ground; therefore routine operation of the subsurface storage facility will produce no pathways for radionuclides to man.

An estimated 180,000 m^3/yr (case A) or 360,000 m^3/yr (case B) of water from storm runoff (assuming annual precipitation of 0.76 m) will be diverted to a retention basin to check for radioactive contamination. The capacity assumed for the retention basin (14,000 m^3 for case A and 27,000 m^3 for case B) is adequate to store about one-half to one-quarter (case B) of the storm runoff from the maximum potential 24-hr precipitation of 0.13 m. The method of disposition of this excess storm runoff is not defined, and discussion of its possible environmental effects requires an engineering decision on drainage area or retention pond size.

The amount of heat generated at the subsurface storage facility will be about 3.8 x 10^7 MJ/yr for case A and 7.2 x 10^7 MJ/yr for case B. This heat will be released directly to the atmosphere through natural convection and conduction through the roof, sides, and bottom of the shielding in the storage facility.

Physical, Chemical, and Thermal Effects. The amount of heat generated at the subsurface storage facility will be 3.8 x 10^7 MJ/yr for case A and 7.2 x 10^7 MJ/yr for case B. This heat will be transferred to the atmosphere by natural convection and by conduction through the roof, sides, and bottom of the shielding in the berm. No surface effects will result from the heat released. The heat load rejected over the entire site will be less than 0.25 to 0.48% of the urban heat load value for a town of 20,000 to 30,000 population.

Radiological Effects. No releases of radioactive material to air, water, or ground are planned during routine operation; therefore, no radiological effects are expected.

Ecological Effects. The burning of approximately 15 m^3/yr of fossil fuel to operate equipment at the facility will result in minor incremental emissions to the atmosphere. No ecological impact will result from these emissions.

No ecological effects are expected from the release of 7.2 x 10^7 MJ/yr of heat to the ground and atmosphere.

8.2.2.3 Environmental Effects Related to Postulated Accidents

No minor accidents resulting in the release of radioactive materials to the biosphere were identified for routine operation of the subsurface storage facility. One moderate accident is postulated to release radioactive material. The scenario is provided in DOE/ET-0028[1] and the accident is listed below.

Accident Number	Description
5.2.1	Waste zirconium hulls canister breached by drop

For this accident, it was assumed that a canister containing 1320 kg of zirconium hulls is breached, thus exposing 0.14 of the contained metal to the atmosphere. About 5.4×10^{-4} of the exposed material is entrained in the atmosphere. A ground level release period of 1 hr and a 1.5-year storage decay time out of the reactor is assumed. The estimated frequency of this accident is 0.2 per year. The radioactive material released during such an event is the same as that given in Table 8.2.1-3 (Section 8.2.1) for the vault storage facility.

Seventy-year dose commitments to the maximum individual were calculated and are identical to those presented in Table 8.2.1-4 (Section 8.2.1). Numerically, the largest of these dose values (dose to the bone received from the uranium only recycle mode) are less than 2% of the dose the individual would have received from naturally occurring sources during the same period.

No serious accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

REFERENCES FOR SECTION 8.2.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

8.2.3 Comparison of Environmental Effects Between Alternatives for Interim Retrievable Waste Storage of Packaged Fuel Residues

There are no planned releases of radioactive materials to air, land, or water during the construction or normal operation of either the vault storage or subsurface storage facilities for fuel residues. However, one moderate accident that would result in the environmental release of radioactive materials was identified and was determined to be common to both storage alternatives.

The quantities of resources needed for construction of the vault and subsurface storage facilities are compared in Table 8.2.3-1. The construction of the subsurface storage facility generally requires less water, materials, and manpower, and much less energy than does construction of the vault storage facility. Resources necessary for operation are the same for both facilities and are given in Table 8.2.1-2 (Section 8.2.1).

TABLE 8.2.3-1. Summary of Resources Committed for Construction of Interim Retrievable Waste Storage Facilities for Fuel Residues

Resource	Vault Storage		Subsurface Storage	
	Case A (1990)[a]	Case B (1995)[b]	Case A (1990)[a]	Case B (1995)[b]
Land,[c] ha	1.4×10^1	2.6×10^1	2.4×10^1	4.7×10^1
Water, m^3	1.5×10^5	2.9×10^5	3.8×10^4	7.2×10^4
Materials				
Steel, MT	3.6×10^4	7.0×10^4	9.0×10^3	1.7×10^4
Copper, MT	2.2×10^1	4.3×10^1	1.1×10^1	2.2×10^1
Lead, MT	1.1×10^2	2.2×10^2	1.1×10^2	2.2×10^2
Lumber, m^3	7.8×10^3	1.5×10^4	2.6×10^3	5.0×10^3
Concrete, m^3	1.5×10^5	2.8×10^5	4.2×10^4	8.0×10^4
Energy				
Propane, m^3	1.1×10^3	2.2×10^3	2.9×10^2	5.5×10^2
Diesel fuel, m^3	1.1×10^4	2.2×10^4	2.9×10^3	5.6×10^3
Gasoline, m^3	7.6×10^3	1.4×10^4	2.0×10^3	3.8×10^3
Electricity, kWh	5.7×10^6	1.1×10^7	1.5×10^6	2.8×10^6
Manpower, man-yr	5.0×10^3	9.6×10^3	1.3×10^3	2.5×10^3

a. Case A is based on the cumulative number of fuel residue canisters and failed equipment canisters from all reprocessing operations through the year 1990.
b. Case B is based on the number of canisters through the year 1995.
c. Land requirements given are for actual areas occupied by the facility. Total land requirements, however, are the same for both alternatives (160 ha).

No significant ecological impacts were identified for either waste storage alternative during construction or operation.

8.3 INTERIM RETRIEVABLE STORAGE OF INTERMEDIATE-LEVEL TRANSURANIC WASTES

8.3 INTERIM RETRIEVABLE STORAGE OF INTERMEDIATE-LEVEL TRANSURANIC WASTES

Intermediate-level transuranic wastes are radioactive wastes that have a surface dose rate of more than 0.2 rem/hr. These wastes are generated and packaged in 55-gal drums at the FRP and transported to an independent storage facility in the event that a Federal repository is not available to accept the wastes.

Most of the waste drums have surface radiation readings well below 10 R/hr. Open-air transfer from the truck to the receiving cell will be permitted for containers with surface radiation readings below 10 R/hr; packages with readings greater than 15 R/hr will require the use of a shielded handling and transfer cask. All intermediate-level transuranic wastes will be handled remotely.

8.3.1 Outdoor Subsurface Storage of Intermediate-Level Transuranic Wastes

The outdoor subsurface storage facility provides storage for intermediate-level transuranic wastes in 55-gal carbon steel drums. The drums are placed in vertical caissons sunk beneath the ground surface. No commercial experience is available for this storage concept although the Idaho National Engineering Laboratory currently has a facility that consists of 26 of these vaults. Alternative subsurface storage concepts involve variations in design and materials. The caisson concept was selected as a technically viable method that is representative of the shallow underground storage alternatives for intermediate-level transuranic wastes and is considered as the reference concept in this discussion.

Capacities considered for retrievable storage of intermediate-level transuranic wastes generated by all FRPs are 1) 85,000 drums through the year 1990 (case A) and 2) 163,000 drums through the year 1995 (case B). A flow diagram illustrating operation, equipment, and materials required for this storage concept is shown in Figure 8.3.1-1.

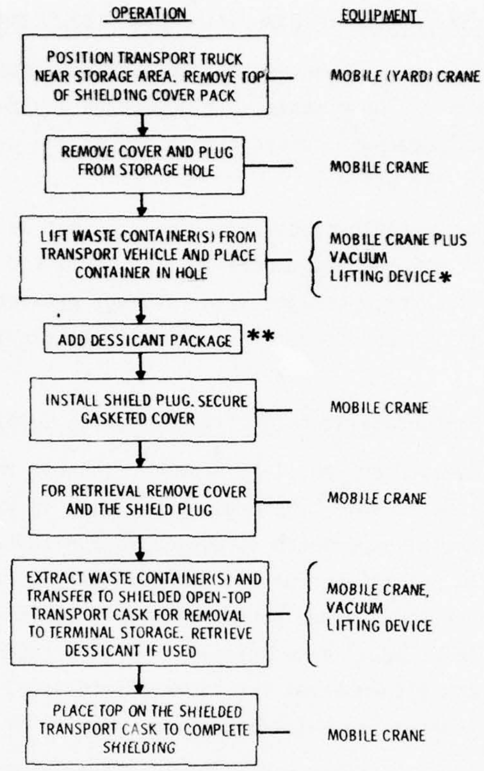
The caisson concept is illustrated in Section 5.3.3 of DOE/ET-0028[1] for a module with a capacity for 2520 drums. Extension of this basic module and multiples of such extensions are required to obtain the needed facility capacity.

8.3.1.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The subsurface storage facility will require approximately 20 ha for case A (storage to 1990) and 38 ha for case B (storage to 1995) at the 800-ha retrievable waste storage facility site.

The estimated water required for facility construction is 1.4×10^4 m^3 for case A (1990) and 2.6×10^4 m^3 for case B (1990); it will be supplied from either the R River at the reference environment (Appendix A) or from wells. Removal of this quantity of water from the R River is small relative to the average annual flow of 3.9×10^9 m^3 and will not interfere with other downstream water uses, or in the event that wells are used, with groundwater supplies.



* IN OPEN-AIR TRANSFERS OF TRU ILW, A SHIELDED HANDLING TRANSFER CASK MAY BE REQUIRED.

** WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 8.3.1-1. Flow Diagram for Receiving and Handling Intermedite-Level Transuranic Wastes at the Outdoor Subsurface Storage Facility

Other resources committed to the construction of the outdoor subsurface storage facility are listed in Table 8.3.1-1.

Construction of 1.6 km of two-lane paved road will be required from the independent storage site to the nearest U.S. highway.

Physical and Chemical Effects. The diversion of up to 2.6 x 10^4 m^3 of water (case B) for construction of the outdoor subsurface storage facility is not expected to have a significant impact on local water supplies. Excavation for the waste drum storage area and the storm water retention pond is not expected to affect groundwater movement. Backfilling of up to 418,000 m^3 of soil (case B) to produce the berm for the storage vaults may cause sediment runoff; however, it can be controlled by ditching and land contouring. The use of up to 38 ha of land (case B) for the outdoor subsurface storage facility is not expected to have a significant impact on local land use.

TABLE 8.3.1-1. Materials and Utilities Required for Construction of the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Resource	Use: Case A (1990)	Use: Case B (1995)
Steel, MT	1.7×10^4	3.2×10^4
Lead, MT	4.0×10^2	7.8×10^2
Lumber, m^3	1.7×10^3	3.2×10^3
Concrete, m^3	1.4×10^4	2.6×10^4
Propane, m^3	1.4×10^2	2.6×10^2
Diesel fuel, m^3	1.4×10^3	2.6×10^3
Gasoline, m^3	8.8×10^2	1.7×10^3
Electricity		
Peak demand, kW	1.4×10^3	2.6×10^3
Total consumption, kWh	6.8×10^5	1.3×10^6
Manpower, man-yr	5.8×10^2	1.1×10^3

Pollutants will be released to the atmosphere through the combustion of up to 4.5×10^3 m^3 of fossil fuels by construction equipment and the generation of dust by grading and excavation. The atmospheric concentrations of combustion products will be well below Federal air quality standards at the waste storage facility fenceline.

Ecological Effects. The ecological impacts from construction will result primarily from the destruction of vegetation cover and the associated displacement of birds and mammals. The maximum facility site (case B) requirements will be about 38 ha and the amount of habitat alteration is not expected to cause serious ecological impacts. An additional area of about 5 ha will be cleared for the access road to the facility site.

Moving earth to create a berm 1.7 m deep with a surface area of about 246,000 m^2 has the potential for creating serious erosion problems. Control measures such as ditching, catch basins, and land contouring will need to be carefully applied to prevent large quantities of silts from being deposited on the land adjoining the facility or removed to nearby surface waters.

Up to 2.6×10^4 m^3 of water will be required during the approximately 10-year construction period. This water will be supplied from either the R River at the reference environment (Appendix A) or from wells near the site.

The release of combustion products from the burning of up to 4.5×10^3 m^3 of fossil fuels during construction will not exceed applicable Federal air quality standards.

The overall impacts of the subsurface waste storage facility for intermediate-level transuranic wastes are judged to be minor and ecologically acceptable.

8.3.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources used during planned operation of the outdoor subsurface storage facility are given in Table 8.3.1-2.

TABLE 8.3.1-2. Materials and Utilities Required for Operation of the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Resource	Average Annual Use Case A (1990)	Case B (1995)
Dessicant, MT	1.2×10^1	1.7×10^1
Diesel fuel, m^3	3.8×10^1	5.3×10^1
Electricity, kWh	3.0×10^5	4.0×10^5
Manpower, man-yr	8.1	1.2×10^1

Process Effluents. No radioactive materials will be released to the biosphere during planned operation of the facility.

The combustion of fossil fuels by vehicles used in the handling and storage operation will release pollutants to the atmosphere. Approximately 50 m^3 of diesel fuel will be burned annually by trucks. The quantities of fuel combustion products released to the environment, however, will be several orders of magnitude below Federal air quality standards for hydrocarbons, nitrogen and sulfur oxides, carbon monoxide, and particulates.

Physical, Chemical, and Thermal Effects. No nonradioactive liquid or solid wastes will be released directly to surface or groundwaters or to land from operation of the outdoor subsurface storage facility. All liquid and solid waste disposal is part of the overall retrievable waste storage facility operation.

Storm drainage of up to an estimated 190,000 m^3/yr of water (assuming an average annual precipitation of 0.76 m) will be diverted to a retention basin to check for radioactive contamination before it is released to the retrievable waste storage facility drainage system. As much as 32,000 m^3 of runoff per 24 hr during a single storm (assumed 24-hr precipitation of 0.13 m) will also be sent to a retention basin.

Consumption of diesel fuel by facility equipment is sufficiently small that the release of combustion products to the atmosphere will be well below Federal air quality standards.

Radiological Effects. No radionuclides will be released to the environment during normal facility operation.

Ecological Effects. Because no pollutants will be released from the outdoor subsurface storage facility, except for small amounts from vehicle exhausts, no ecological effects are expected from normal facility operation.

8.3.1.3 Effects Related to Postulated Accidents

Two accidents are postulated to release radioactive materials; these are classified as moderate accidents. The scenarios for these accidents are provided in DOE/ET-0028,[1] and the accidents are listed below.

Accident Number	Description
5.3.5	Fire in storage stack
5.3.6	Tornado strikes transuranic storage area during stacking operation

The tornado strike during stacking operation was judged to be the most severe of these two accidents and is treated as the representative accident. This accident involves the rupture of three containers holding failed equipment from the retrievable waste storage facility and the release of 0.001 of their contents to the atmosphere. The radionuclides released are given in Table 8.3.1-3.

TABLE 8.3.1-3. Radionuclides Released to the Atmosphere from a Moderate Accident in the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Radionuclide	Release, Ci
^{238}Pu	2.3×10^{-2}
^{239}Pu	1.6×10^{-3}
^{241}Pu	7.1×10^{-1}
^{241}Am	1.2×10^{-3}

The 1-year dose and 70-year dose commitment to the maximum individual from release of these radioactive materials are given in Tables 8.3.1-4 and 8.3.1-5 respectively. Doses resulting from this moderate accident are all less than 1×10^{-6} rem/yr and represent only a small fraction of the doses received from naturally occurring sources.

No serious accidents were identified within the design basis of the facility.

TABLE 8.3.1-4. One-Year Dose to the Maximum Individual from a Moderate Accident in the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	6.3×10^{-16}	1.1×10^{-15}	1.1×10^{-15}	1.1×10^{-15}	1.1×10^{-15}
Inhalation		1.2×10^{-9}		8.1×10^{-8}	2.7×10^{-8}
Total	6.3×10^{-16}	1.2×10^{-9}	1.1×10^{-15}	8.1×10^{-8}	2.7×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the site center with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.0×10^{-9} sec/m^3.

TABLE 8.3.1-5. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident in the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	6.3×10^{-16}	1.1×10^{-15}	1.1×10^{-15}	1.1×10^{-15}	1.1×10^{-15}
Inhalation		3.7×10^{-8}		2.0×10^{-7}	8.1×10^{-7}
Total	6.3×10^{-16}	3.7×10^{-8}	1.1×10^{-15}	2.0×10^{-7}	8.1×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 10 km from the site with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.0×10^{-9} sec/m^3.

REFERENCES FOR SECTION 8.3.1

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

8.3.2 Indoor Shielded Storage of Intermediate-Level Transuranic Wastes

The indoor shielded interim storage facility is a reinforced concrete cast-in-place structure designed to store intermediate-level transuranic wastes packaged in 55-gal drums. No commercial experience is available for this storage concept. Alternative indoor shielded storage concepts involve variations in design, cell size, and building materials. The design selected was considered to be representative for the indoor shielded storage concept.

The indoor shielded storage facility at the retrievable waste storage facility has the capacity to store the intermediate-level transuranic wastes generated by all FRPs through 1990 (case A, 85,000 drums) and through 1995 (case B, 163,000 drums). A flow diagram illustrating operation and equipment is shown in Figure 8.3.2-1.

A typical cell in the indoor shielded facility can hold 500 drums of waste. Section 5.3.4 of DOE/ET-0028[1] shows a plan of a module with 40 such cells. The required facility capacity is obtained by building multiples of such cells.

8.3.2.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and facility construction have an effect on the environment and the natural resources of the area. The following information is provided to form a basis for evaluating these effects.

Resource Commitments. The amount of land committed for the indoor shielded storage facility depends on the capacity of the facility. For case A, which covers the storage of intermediate-level transuranic wastes through 1990, 0.8 ha of land will be required; for case B, storage capacity through 1995, 1.6 ha of land is needed.

Water used during the construction period for case A (1990) will be about 2.1×10^4 m^3 and for case B (1995), 4.1×10^4 m^3. This water will be supplied either from the R River in the reference environment (Appendix A) or from wells. Removal of this volume of water from the river over a construction period of several years is small relative to the average annual river flow of 3.9×10^9 m^3; thus other downstream water uses will not be affected.

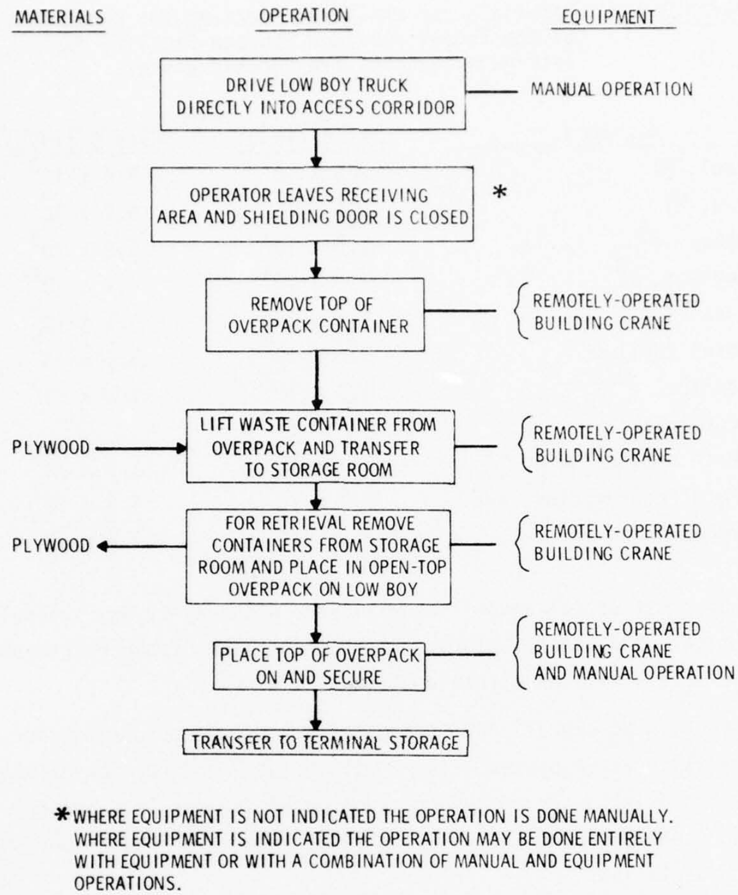


FIGURE 8.3.2-1. Flow Diagram for Handling Intermediate-Level Transuranic Wastes at the Indoor Shielded Storage Facility

Other resources committed to the construction of the indoor shielded storage facility are listed in Table 8.3.2-1.

Construction of 1.6 km of two-lane paved road will be required from the independent storage site to the nearest U.S. highway.

Physical and Chemical Effects. Water needed during construction of the indoor shielded storage facility (2.1×10^4 m^3 for case A and 4.1×10^4 m^3 for case B) will be supplied from the R River or from wells. This volume of water use will not conflict with other surface or groundwater uses.

Grading and excavation during construction will generate fugitive dust. In addition, there will be atmospheric release of fossil fuel combustion products (sulfur and nitrogen oxides, hydrocarbons, and carbon monoxide) from construction equipment and vehicle traffic. Quantities of these materials discharged to the atmosphere will be within the limits set by Federal air quality standards.

TABLE 8.3.2-1. Materials and Utilities Required for Construction of the Indoor Shielded Storage Facility for Intermediate-Level Transuranic Wastes

Resource	Use Case A (1990)	Use Case B (1995)
Steel, MT	3.8×10^3	7.4×10^3
Lead, MT	5.1×10^1	9.9×10^1
Lumber, m^3	1.5×10^3	2.9×10^3
Concrete, m^3	2.4×10^4	4.7×10^4
Propane, m^3	1.6×10^2	3.1×10^2
Diesel fuel, m^3	1.6×10^3	3.1×10^3
Gasoline, m^3	1.0×10^3	2.0×10^3
Electricity		
Peak demand, kW	1.7×10^3	3.3×10^3
Total consumption, kWh	7.7×10^5	1.5×10^6
Manpower, man-yr	6.8×10^2	1.3×10^3

Noise caused by construction activities will vary with day-to-day schedules, variations in equipment operations, and other factors. At the fenceline of the retrievable waste storage facility, the noise levels will be within applicable limits.

Ecological Effects. No significant ecological impacts from construction of the indoor shielded storage facility are expected. There will be some destruction of vegetation and displacement of birds and animals caused by construction of the facility and the 1.6-km access road. No separate or additional transportation requirements for the indoor shielded storage facility have been identified.

During an assumed 3- to 4-year construction period for the maximum capacity facility (case B), water use will be about 4.1×10^4 m^3. This volume of water will be supplied by the R River; it represents an insignificant fraction of the average annual river flow of 3.9×10^9 m^3. No environmental impacts on the river ecosystem are expected from this volume removal.

About 2500 m^3 of fossil fuels will be consumed during construction of the maximum capacity facility (case B). Pollutants released from the burning of these fuels will result in air concentrations below the Federal air quality standards. No ecological impacts are expected as a result of fuel consumption.

8.3.2.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and natural resources of the area. The following information is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources used during planned operation of the indoor shielded storage facility for intermediate-level transuranic wastes are listed in Table 8.3.2-2.

TABLE 8.3.2-2. Materials and Utilities Required for Operation of the Indoor Shielded Storage Facility for Intermediate-Level Transuranic Wastes

Resource	Average Annual Use Case A (1990)	Case B (1995)
Plywood (1/2 in.), m^2	4.2×10^3	5.7×10^3
Diesel fuel, m^3	1.9×10^1	2.7×10^1
Electricity, kWh	3.5×10^5	5.0×10^6
Manpower, man-yr	8.1	1.2×10^1

Process Effluents. During normal facility operation no radioactive or nonradioactive liquid or solid wastes will be released directly to the land or surface waters. Sanitary waste water will be sent to the common retrievable waste storage facility sewer.

For the maximum capacity facility (case B) approximately 27 m^3 of diesel fuel will be burned annually by the vehicles used in the waste handling and storage operations. Concentrations of combustion products released to the atmosphere from this small fuel consumption will be well below the Federal air quality limits for hydrocarbons, carbon monoxide, and sulfur and nitrogen oxides.

Physical, Chemical, and Thermal Effects. With no pollutants being released to ground or surface waters, and a small discharge of air pollutants from the combustion of fossil fuels, little environmental impact is expected from the normal operation of the facility. Up to 1.6 ha of land occupied by the indoor shielded storage facility will be unavailable for other uses during the life of the facility.

Radiological Effects. Because no releases of radioactive materials to the biosphere are planned during normal facility operation, no radiological effects are expected.

Ecological Effects. Normal operation of the indoor shielded storage facility will result in no significant environmental effects. The only nonradioactive materials identified to be released from the facility during normal operation are emissions from burning small quantities of fossil fuels. Approximately 27 m^3/yr of diesel fuel will be used but will generate only insignificant levels of air pollutants.

Ecological impacts from noise and human activities associated with facility operation will be insignificant.

8.3.2.3 Environmental Effects Related to Postulated Accidents

Three accidents are postulated to release radioactive materials in amounts greater than those released during minor accidents. These are classified as moderate accidents and are listed below.

Accident Number	Description
5.3.5	Fire in storage stack
5.3.6	Tornado strike to transuranic storage area during stacking operation
5.3.8	Canister drop from bridge crane

The canister drop from bridge crane operation (Accident 5.3.8) was judged to be the most severe of these three accidents and is treated as the representative accident. This accident involves the rupturing of a drum of compacted filter media. Rupture occurs when the drum is dropped from the bridge crane, thus releaseing 5 x 10^{-5} of the contents to the atmosphere over a 1-hr period. Source terms for this accident are given in Table 8.3.2-3.

TABLE 8.3.2-3. Radionuclides Released to the Atmosphere from a Canister Drop from the Bridge Crane at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

	Release, Ci		
Radionuclide	U and Pu Recycle	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2
^{90}Sr	1.5 x 10^{-4}	1.8 x 10^{-4}	1.6 x 10^{-4}
^{95}Nb	1.9 x 10^{-5}	2.1 x 10^{-5}	1.9 x 10^{-5}
^{106}Ru	4.8 x 10^{-4}	4.8 x 10^{-4}	4.2 x 10^{-4}
^{125m}Te	6.0 x 10^{-6}	6.2 x 10^{-6}	5.5 x 10^{-6}
^{127m}Te	1.1 x 10^{-6}	1.2 x 10^{-6}	1.1 x 10^{-6}
^{129}I	8.8 x 10^{-11}	9.2 x 10^{-11}	8.2 x 10^{-11}
^{134}Cs	3.0 x 10^{-4}	3.4 x 10^{-4}	3.0 x 10^{-4}
^{137}Cs	2.3 x 10^{-4}	2.6 x 10^{-4}	2.3 x 10^{-4}
^{144}Ce	6.0 x 10^{-4}	7.0 x 10^{-4}	6.2 x 10^{-4}
^{154}Eu	1.5 x 10^{-5}	1.5 x 10^{-5}	1.4 x 10^{-5}
^{238}Pu	2.8 x 10^{-3}	8.7 x 10^{-6}	1.1 x 10^{-3}
^{239}Pu	1.8 x 10^{-4}	8.1 x 10^{-7}	1.4 x 10^{-4}
^{240}Pu	3.6 x 10^{-4}	1.3 x 10^{-6}	2.2 x 10^{-4}
^{241}Pu	9.0 x 10^{-2}	3.1 x 10^{-4}	5.5 x 10^{-2}

The first-year dose and 70-year dose commitment to the maximum individual from release of these radionuclides are given in Tables 8.3.2-4 and 8.3.2-5 respectively. Numerically, the largest dose from this accident amounts to about 4% of the total dose the individual would have received from naturally occurring sources over the 70-year period.

REFERENCES FOR SECTION 8.3.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington DC, in press.

8.3.3 Comparison of Environmental Effects Between Alternatives for Interim Retrievable Storage of Intermediate-Level Transuranic Wastes

There is little difference between the predicted environmental consequences of construction and operation of the outdoor subsurface storage and the indoor shielded storage facilities for intermediate-level transuranic wastes.

Under planned operating conditions, no radioactive materials will be released to the environment from either facility. The postulated most severe moderate accident, a tornado strike during the stacking operation, is the same for both facilities.

TABLE 8.3.2-4. First-Year Dose to the Maximum Individual from a Canister Drop from the Bridge Crane at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle		
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	4.2×10^{-4}	1.6×10^{-7}	2.7×10^{-2}	9.9×10^{-3}
Total	4.2×10^{-4}	1.8×10^{-7}	2.7×10^{-2}	9.9×10^{-3}
		U Recycle, Pu in SHLW		
Air submersion	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation	4.6×10^{-6}	1.7×10^{-7}	2.8×10^{-4}	5.8×10^{-5}
Total	4.6×10^{-6}	1.9×10^{-7}	2.8×10^{-4}	5.8×10^{-5}
		U Recycle, Pu Stored as PuO_2		
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	2.2×10^{-4}	1.5×10^{-7}	1.2×10^{-2}	5.3×10^{-3}
Total	2.2×10^{-4}	1.7×10^{-7}	1.2×10^{-2}	5.3×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the site center with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

TABLE 8.3.2-5. 70-Year Dose Commitment to the Maximum Individual from a Canister Drop from the Bridge Crane at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle		
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	1.3×10^{-2}	1.6×10^{-7}	6.8×10^{-2}	2.9×10^{-1}
Total	1.3×10^{-2}	1.8×10^{-7}	6.8×10^{-2}	2.9×10^{-1}
		U Recycle, Pu in SHLW		
Air submersion	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation	7.5×10^{-5}	1.7×10^{-7}	5.3×10^{-4}	1.2×10^{-3}
Total	7.5×10^{-5}	1.9×10^{-7}	5.3×10^{-4}	1.2×10^{-3}
		U Recycle, Pu Stored as PuO_2		
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	6.9×10^{-3}	1.5×10^{-7}	3.0×10^{-2}	1.4×10^{-1}
Total	6.9×10^{-3}	1.7×10^{-7}	3.0×10^{-2}	1.4×10^{-1}

A comparison of the resources required for construction of the outdoor subsurface and the indoor shielded storage facilities is given in Table 8.3.3-1. A comparison of the commitment of resources for facility operation is given in Table 8.3.3-2. The requirements for water, materials, energy, and manpower are generally comparable for the construction and operation of the outdoor subsurface and the indoor shielded storage facilities. From the standpoint of potential environmental impact, neither facility has a clear advantage over the other.

TABLE 8.3.3-1. Summary of the Resources Committed for the Construction of Interim Retrievable Storage Facilities for Intermediate-Level Transuranic Wastes

Resource	Outdoor Subsurface Storage: Case A (1990)[a]	Outdoor Subsurface Storage: Case B (1995)[b]	Indoor Shielded Storage: Case A (1990)[a]	Indoor Shielded Storage: Case B (1995)[b]
Land, m^2	2.0×10^5	3.8×10^5	8.1×10^3	1.6×10^4
Water, m^3	1.4×10^4	2.6×10^4	2.1×10^4	4.1×10^4
Materials				
Steel, MT	1.7×10^4	3.2×10^4	3.8×10^3	7.4×10^3
Lead, MT	4.0×10^2	7.8×10^2	5.1×10^1	9.9×10^1
Lumber, m^3	1.7×10^3	3.2×10^3	1.5×10^3	2.9×10^3
Concrete, m^3	1.4×10^4	2.6×10^4	2.4×10^4	4.7×10^4
Energy				
Propane, m^3	1.4×10^2	2.6×10^2	1.6×10^2	3.1×10^2
Diesel fuel, m^3	1.4×10^3	2.6×10^3	1.6×10^3	3.1×10^3
Gasoline, m^3	8.8×10^2	1.7×10^3	1.0×10^3	2.0×10^3
Electricity, kWh	6.8×10^5	1.3×10^6	7.7×10^5	1.5×10^6
Manpower, man-yr	5.8×10^2	1.1×10^3	6.8×10^2	1.3×10^3

a. Case A is based on the cumulative number of drums of waste generated by all fuel reprocessing plants through the year 1990.
b. Case B is based on the number of drums of waste generated through the year 1995.

TABLE 8.3.3-2. Summary of the Average Annual Resource Commitments for Operating Interim Retrievable Storage Facilities for Intermediate-Level Transuranic Wastes

Resource	Outdoor Subsurface Storage: Case A (1990)[a]	Outdoor Subsurface Storage: Case B (1995)[b]	Indoor Shielded Storage: Case A (1990)[a]	Indoor Shielded Storage: Case B (1995)[b]
Materials				
Plywood (1/2 in.), m^3	--	--	4.2×10^3	5.7×10^3
Energy				
Diesel fuel, m^3	3.8×10^1	5.3×10^1	1.9×10^1	2.7×10^1
Electricity, kWh	3.0×10^5	4.0×10^5	3.5×10^5	5.0×10^5
Manpower, man-yr	8.1	1.2×10^1	8.1	1.2×10^1

a. Case A is based on the cumulative number of drums of waste generated by all fuel reprocessing plants through the year 1990.
b. Case B is based on the number of drums of waste generated through the year 1995.

Use of fuel recycle modes other than uranium recycle only will produce no differences in environmental impact resulting from either the outdoor or indoor storage options.

8.4 INTERIM RETRIEVABLE STORAGE OF LOW-LEVEL TRANSURANIC WASTES

8.4 INTERIM RETRIEVABLE STORAGE OF LOW-LEVEL TRANSURANIC WASTES

Low-level transuranic wastes are radioactive wastes that have a surface dose rate of less than 0.2 rem/hr and can be handled by direct contact. These wastes are generated in 55-gal drums or in 4-m^3 steel boxes at the fuel reprocessing plant (FRP) and the mixed-oxide fuel fabrication plant (MOX FFP). Facilities may be required for the interim storage of low-level transuranic wastes in the event that a Federal repository for final isolation is not available to accept the wastes. In this case, low-level transuranic wastes may be stored at the FRP, MOX FFP, or at an independent storage facility. This section addresses the storage of these wastes only at the retrievable waste storage facility. Two interim storage concepts are considered: outdoor surface storage and indoor unshielded storage. Outdoor surface storage is the reference concept used in Section 5.4 of this report.

8.4.1 Outdoor Surface Storage of Low-Level Transuranic Wastes (DOE/ET-0028 Sec. 5.3.1)

The outdoor surface storage facility is designed to store low-level transuranic wastes contained in 55-gal drums and 4-m^3 steel boxes on an asphalt slab above ground. The drums and boxes are ultimately covered by an earth fill for weather protection. Such facilities for storing low-level transuranic wastes are used at the Idaho National Engineering Laboratory (INEL). Extensive experience at INEL led to selection of this method for the reference concept. Alternatives to this concept include facilities with different methods for providing weather protection and facilities with no weather protection.

Cases considered for outdoor surface storage of low-level transuranic wastes at a retrievable waste storage facility are the capacity to store such wastes generated by all operating FRPs and MOX FFPs through the year 1990 (case A, 65,000 55-gal drums) and through the year 1995 (case B, 130,000 55-gal drums). Figure 8.4.1-1 is a flow diagram showing operation, materials, and equipment involved in the storage concept. A typical module has storage capacity for 10,000 55-gal drums.

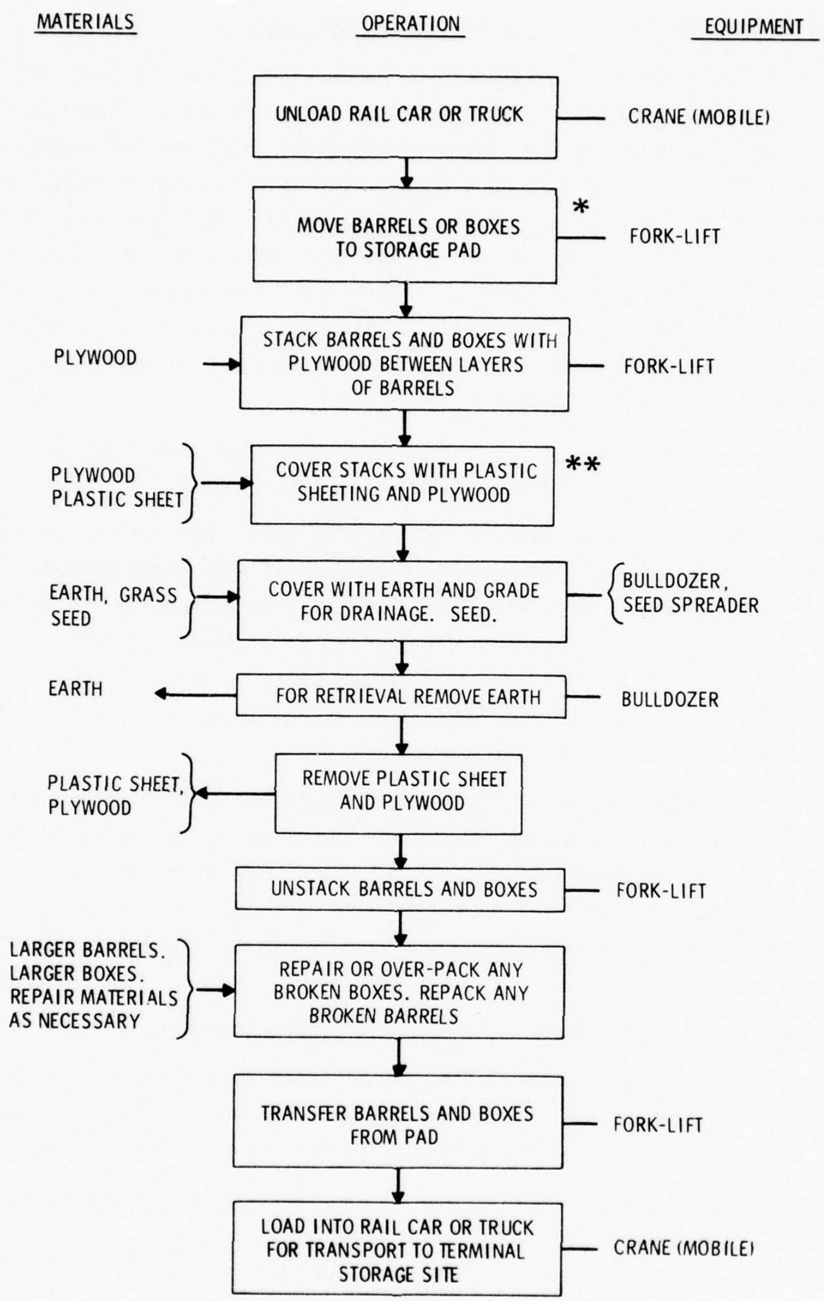
8.4.1.1 Environmental Effects Related to Facility Construction

Site preparation and construction of the outdoor surface storage facility may have an impact on the local environment and the natural resources of the surrounding area. The following discussion is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The outdoor surface storage facility will occupy about 1.6 ha for case A (1990) and 3.2 ha for case B (1995). The storage facility will be located within the 800-ha site set aside for the retrievable waste storage facility.

Water used during construction will be about 5.5×10^2 m^3 for case A and 1.3×10^3 m^3 for case B. Commitments of other resources are given in Table 8.4.1-1. Use of these amounts of resources is small and is judged to be of little environmental consequence.

A 1.6-km two-lane paved road will be constructed to connect the retrievable waste storage facility to the nearest U.S. highway.



* THE CARGO CARRIER MAY BE TRANSPORTED FROM THE RAIL CAR TO THE STORAGE PAD AND OPENED THERE. IF THE CARGO CARRIERS ARRIVE BY TRUCK, THE TRUCK CAN BE DRIVEN DIRECTLY TO THE PAD FOR UNLOADING.

** WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 8.4.1-1. Flow Diagram for Receiving and Handling Low-Level Transuranic Wastes at the Outdoor Surface Storage Facility

TABLE 8.4.1-1. Materials and Utilities Required for the Construction of the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Resource	Use	
	Case A (1990)	Case B (1995)
Steel, MT	230	460
Copper, MT	5.9	12
Lumber, m^3	65	130
Concrete, m^3	490	980
Propane, m^3	4.6	9.1
Diesel fuel, m^3	46	91
Gasoline, m^3	33	65
Electricity, kWh	<10,000	<10,000
Manpower, man-yr	29	58

Physical and Chemical Effects. About 13,000 m^3 of water will be used during construction of the maximum capacity facility (case B). This water will be supplied from the R River at the reference environment (Appendix A). If this volume of water were removed from the river during one year, it would amount to less than 0.01% of the mean annual flow of 3.9×10^9 m^3; therefore withdrawal of this amount of water will not interfere with other downstream water uses. Excavation for the waste storage area and storm water retention ponds, and backfilling for the earth berm surrounding the storage area is not expected to affect groundwater movement. There may be some water erosion of the area cleared for construction, but this can be controlled by ditching and land contouring. No significant siltation of nearby surface waters is expected from construction activities.

There will be some releases of air pollutants through the burning of fuel by construction equipment and the generation of fugitive dust by grading and excavation. These releases will be small and are not expected to have significant environmental impacts.

Ecological Effects. Construction of the outdoor surface storage facility will disturb approximately 3.2 ha of land, thus causing destruction of vegetation and displacement of birds and mammals. In addition, land will be cleared for a 1.6-km two-lane paved road to connect the facility to an existing highway. This loss of wildlife habitat is not expected to have significant ecological consequences.

The maximum withdrawal of 1,300 m^3 of water from the R River during construction will have little effect on the river ecosystem. The water intake will require proper screening to limit the removal of fish and entrainment of other aquatic organisms along with the facility water.

Air pollutants produced by the burning of about 170 m^3 of fossil fuels and the generation of fugitive dust during construction will produce concentrations of dust and fuel combustion products at the site boundary that are well below Federal air quality standards. The impact of these air contaminants on the land and surface waters near the site will not seriously affect the surrounding plants and animals.

Soil erosion at the construction site can be controlled by ditching and land contouring, and the siltation of nearby land and surface waters is not expected to cause ecological problems.

8.4.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources used during operation of the outdoor surface storage facility for low-level transuranic wastes are given in Table 8.4.1-2.

TABLE 8.4.1-2. Materials and Utilities Required for the Operation of the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Resource	Average Annual Use Case A (1990)	Average Annual Use Case B (1995)
Plywood (1/2 in.), m^2	3.4×10^3	4.7×10^3
Plastic sheet, m^2	2.1×10^3	3.0×10^3
Diesel fuel, m^3	1.5×10^1	2.3×10^1
Electricity, kWh	2.3×10^5	3.2×10^5
Manpower, man-yr	3.2	4.3

Process Effluents. No radioactive materials will be released to the biosphere during normal operation of the outdoor surface storage facility.

During facility operation trucks will be used for various storage and handling operations. Maximum annual fuel usage (case B) will be approximately 23 m^3. Assuming that the average truck will travel 4×10^3 km/m^3 (10 mpg) of fuel and that pollutant emission factors are similar to those used by the Environmental Protection Agency,(2) annual emissions have been estimated and are listed in Table 8.4.1-3.

TABLE 8.4.1-3. Air Pollutants Released by Trucks During Operation of the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Pollutant	Amount Released, MT/yr
Hydrocarbons	0.001
Nitrogen oxides	0.004
Carbon monoxide	0.2
Sulfur oxides	0.002
Particulates	0.007

There will be no direct releases of nonradioactive liquid or solid wastes to the land or to surface or ground waters from the outdoor surface storage facility. All liquid and solid waste disposal will be part of the overall retrievable waste storage facility.

For the maximum size facility (case B), storm drainage is estimated at 9600 m^3/yr (assuming an average annual precipitation of 0.76 m). Runoff will be diverted into 13 retention basins to check for radioactive contamination before it is released to the retrievable waste storage drainage system.

Physical, Chemical, and Thermal Effects. Atmospheric effects resulting from operation of this facility will be limited to air quality impacts caused by the release of fossil fuel combustion products by service vehicles. Annual average and maximum ground level concentrations of pollutants released by trucks were computed using atmospheric dispersion ($\overline{\chi}/Q'$) values for a ground level release. These concentrations are listed in Table 8.4.1-4. Pollutant concentrations at the fenceline, both maximum and average, are well below Federal air quality limits.

TABLE 8.4.1-4. Comparison of Federal Air Quality Standards with Fenceline Concentrations (1.6 km) of Air Pollutants Released During Operation of the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

	Concentration at the Facility Fenceline, $\mu g/m^3$		Federal Air Quality Standards[a]	
Pollutant	Maximum	Average	Standard	Period of Determination
Hydrocarbons	6.0×10^{-5}	4.0×10^{-5}	1.6×10^{2}	Maximum 3 hr
Nitrogen oxides	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{2}	Annual arithmetic mean
Carbon monoxide	8.0×10^{-2}	5.0×10^{-3}	4.0×10^{4}	Maximum 1 hr
Sulfur oxides	8.0×10^{-6}	5.0×10^{-6}	8.0×10^{1}	Annual arithmetic mean
Particulates	4.0×10^{-5}	3.0×10^{-5}	7.5×10^{1}	Annual geometric mean

a. Source: A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

Atmospheric pollutants will be deposited on local surfaces. At the reference site, the point of maximum pollutant deposition is 0.4 km from the facility in the north sector. Table 8.4.1-5 lists the pollutants deposited in this area. No environmental effects from these classes of pollutants will result from facility operation.

TABLE 8.4.1-5. Air Pollutant Deposition 0.4 km from the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Pollutant	Deposition, g/m^2-yr
Hydrocarbons	7.0×10^{-5}
Nitrogen oxides	2.0×10^{-4}
Carbon monoxide	9.0×10^{-3}
Sulfur oxides	9.0×10^{-6}
Particulates	4.0×10^{-5}

Radiological Effects. No radioactive materials will be released to the environment during normal operation of the outdoor surface storage facility; therefore no radiological effects are expected.

Ecological Effects. No ecological effects of any consequence will result during normal operation of the outdoor surface storage facility. Approximately 23 m^3 of fossil fuel will be burned per year during normal operation of the maximum capacity facility (case B). The resulting air pollutants will have an insignificant ecological effect.

No unusual or unique nonradiological effluents have been identified for this facility.

8.4.1.3 Environmental Effects Related to Postulated Accidents

One accident is postulated to release radioactive material; it is classified as a moderate accident and is listed below. The scenario for this accident is provided in DOE/ET-0028.[1]

Accident Number	Description
5.3.6	Tornado strikes transuranic storage area during stacking operation

This accident involves the rupture of three containers holding failed equipment from the retrievable waste storage facility and the release of 0.001 of their contents to the atmosphere. The radionuclides released are given in Table 8.4.1-6.

TABLE 8.4.1-6. Radionuclides Released to the Atmosphere During a *Moderate Accident at the* Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Radionuclide	Release, Ci
^{238}Pu	8.6×10^{-4}
^{239}Pu	5.9×10^{-5}
^{241}Pu	2.6×10^{-2}
^{241}Am	4.3×10^{-5}

The 1-year dose and 70-year dose commitment to the maximum individual from release of these radioactive materials are given in Tables 8.4.1-7 and 8.4.1-8 respectively. The largest doses calculated for the 70-year dose commitment to the maximum individual are less than 0.1% of the dose the individual would have received from naturally occurring radiation sources during the same period. No measurable effects are expected from these exposures.

No serious accidents were postulated within the design basis of the facility.

TABLE 8.4.1-7. One-Year Dose to the Maximum Individual from a Moderate Accident at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	1.1×10^{-15}	6.3×10^{-16}	6.3×10^{-16}	6.3×10^{-16}	6.3×10^{-16}
Inhalation		1.2×10^{-9}	0	8.1×10^{-8}	2.7×10^{-8}
Total	1.1×10^{-15}	1.2×10^{-9}	6.3×10^{-16}	8.1×10^{-8}	2.7×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 10 km from the site with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.0×10^{-9} sec/m^3.

TABLE 8.4.1-8. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident at the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	1.1×10^{-15}	6.3×10^{-16}	6.3×10^{-16}	6.3×10^{-16}	6.3×10^{-16}
Inhalation		3.7×10^{-8}	0	2.0×10^{-7}	8.1×10^{-7}
Total	1.1×10^{-15}	3.7×10^{-8}	6.3×10^{-16}	2.0×10^{-7}	8.1×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the site center with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.0×10^{-9} sec/m^3.

REFERENCES FOR SECTION 8.4.1

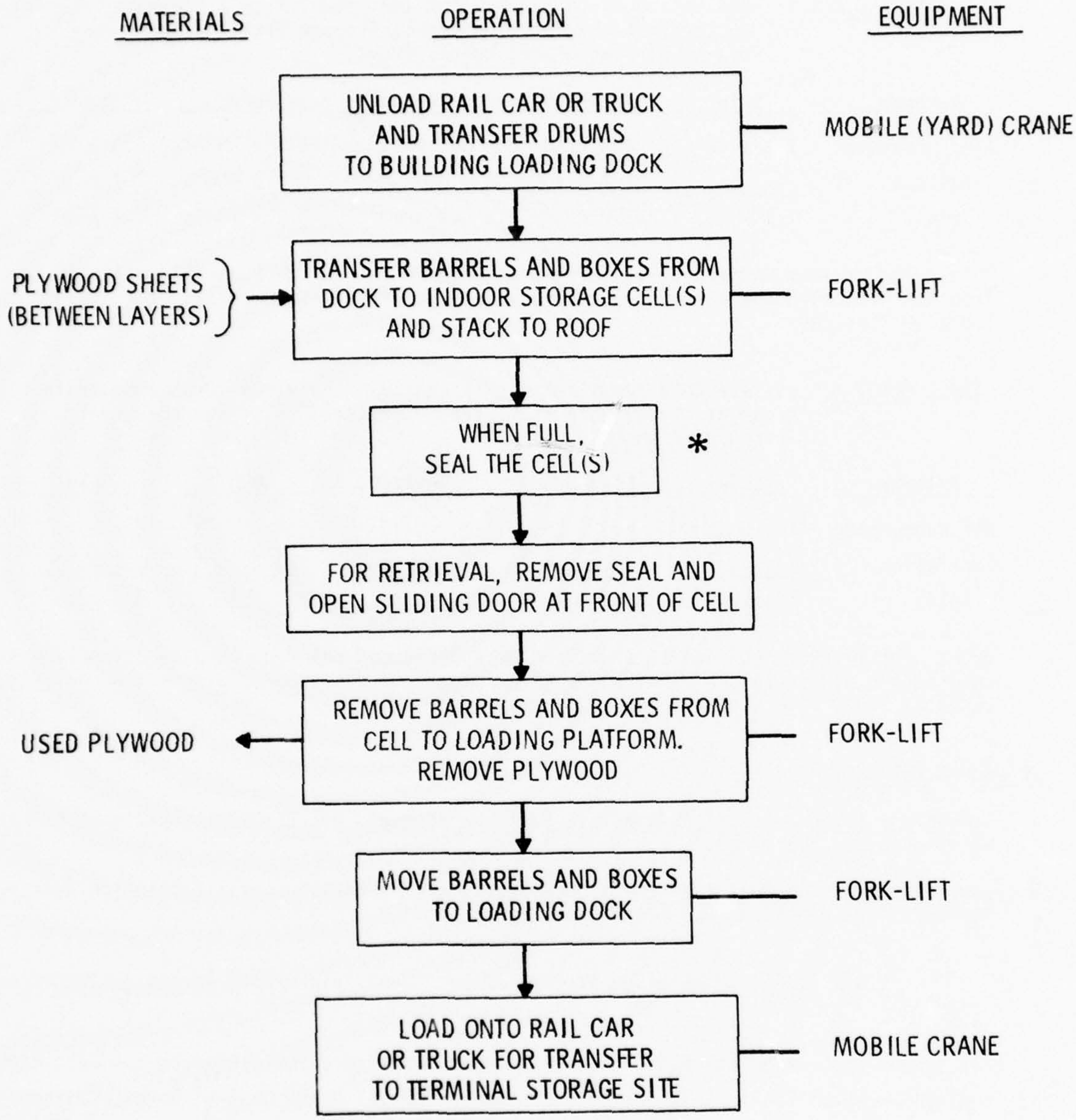
1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. Compilation of Air Pollutant Emission Factors, AP-42, Environmental Protection Agency, Research Triangle Park, NC, April 1973.

8.4.2 Indoor Unshielded Storage of Low-Level Transuranic Wastes
(DOE/ET-0028 Sec. 5.3.2)

The indoor unshielded storage facility is a modular thin-slab-reinforced concrete structure for storing low-level transuranic wastes contained in 55-gal drums or 4-m^3 boxes. Alternatives involve variations in design of the structure and in building materials. This concept was selected as a technically viable design that is representative of the indoor unshielded storage concept.

Cases considered for interim indoor unshielded storage of low-level transuranic wastes at an independent retrievable waste storage facility are the capacity to store such wastes generated by all operating fuel reprocessing plants (FRP) and mixed-oxide fuel fabrication plants (MOX FFP) through the year 1990 (case A, 65,000 55-gal drums) and through the year 1995 (case B, 130,000 55-gal drums). Figure 8.4.2-1 shows the operations, materials, and equipment used for this storage concept.



* WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 8.4.2-1. Flow Diagram for Receiving and Handling Low-Level Transuranic Wastes at the Indoor Unshielded Storage Facility

As Section 5.3.2 of DOE/ET-0028[1] shows, the design of two typical cells for indoor unshielded storage have a capacity to store 8400 55-gal drums of low-level transuranic wastes. The desired capacity for the facility is obtained by building multiples of these modules.

8.4.2.1 Environmental Effects Related to Facility Construction

Site preparation and construction of the indoor unshielded storage facility may have an impact on the local environment and the natural resources of the surrounding area. The following discussion is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The indoor unshielded storage facility will occupy about 0.53 ha for case A (storage of 65,000 55-gal drums through 1990) and 1.0 ha for case B (storage of 130,000 55-gal drums through 1995). The storage facility will be located within the 800-ha site set aside for the retrievable waste storage facility.

Water used during construction will be approximately 3.1×10^3 m^3 for case A and 6.2×10^3 m^3 for case B. Other resources needed for the facility are given in Table 8.4.2-1.

A 1.6-km two-lane paved road will be constructed to connect the facility to an existing U.S. highway.

TABLE 8.4.2-1. Materials and Utilities Required for Construction of the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes

Resource	Use: Case A (1990)	Use: Case B (1995)
Steel, MT	4.6×10^2	9.3×10^2
Lumber, m^3	7.7×10^1	1.6×10^2
Concrete, m^3	3.9×10^3	7.8×10^3
Propane, m^3	3.1×10^1	6.2×10^1
Diesel fuel, m^3	3.1×10^2	6.2×10^2
Gasoline, m^3	1.6×10^2	3.1×10^2
Electricity		
Peak demand, kW	2.3×10^2	4.7×10^2
Total consumption, kWh	1.6×10^5	3.1×10^5
Manpower, man-yr	9.5×10^1	2.0×10^2

Physical and Chemical Effects. Construction of the indoor unshielded storage facility for low-level transuranic wastes will require about 0.3 ha for the maximum size facility (case B), which will be located on the 800-ha interim retrievable waste storage site. The land allotted for the indoor unshielded storage facility will not affect local land use.

Approximately 6.2×10^3 m^3 of water will be required during construction of the indoor unshielded storage facility (case B) and will be supplied from the R River at the reference environment (Appendix A). This volume of water is less than 0.001% of the average river flow and will not interfere with other river water uses.

The burning of about 990 m^3 of fossil fuels during construction of the maximum size facility (case B) will release combustion products to the atmosphere. The estimated concentrations of these pollutants (hydrocarbons, carbon monoxide, particulates, and nitrogen and sulfur oxides) at the site fenceline will be well below the limits specified in Federal air quality standards and will not limit the use of the surrounding land for other purposes. Fugitive dust may also be generated during construction. This problem can be controlled by wetting the soil surface; most of the dust is expected to be confined to the retrievable storage site.

Ecological Effects. There will be some destruction of vegetation and displacement of birds and mammals during facility and access road construction. This land disturbance will be small and is not expected to seriously affect nearby plant and animal populations.

The small fraction (<0.001%) of the annual mean R River flow that will be required during facility construction will not affect the river ecosystem. Proper screening of the river water intake will limit the entrainment of aquatic organisms in the water withdrawn for construction purposes.

The fossil fuel combustion products released to the atmosphere from the burning of about 990 m^3 of fuel during facility construction will not exceed, at the site fenceline, the limits set by Federal air quality standards. Total facility construction will take place over several years and the air pollutants from vehicle operation will accordingly be spread out over the same period.

8.4.2.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of facility operation.

Resource Commitments. The resources required for planned operation of the indoor unshielded storage facility for low-level transuranic wastes are given in Table 8.4.2-2.

TABLE 8.4.2-2. Materials and Utilities Required for Operation of the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes

Resource	Average Annual Use: Case A (1990)	Case B (1995)
Plywood (1/2 in.), m^2	4.6×10^3	6.5×10^3
Diesel fuel, m^3	7.6	1.1×10^1
Electricity, MWh	2.3×10^5	3.2×10^5
Manpower, man-yr	3.2	4.3

Process Effluents. No radioactive materials will be released to the environment during normal operation of the indoor unshielded storage facility. There will also be no discharge of nonradioactive liquid effluents to the adjacent land or surface waters.

Some pollutants will be released to the atmosphere by the combustion of approximately 11 m^3/yr of diesel fuel.

Physical, Chemical, and Thermal Effects. The only pollutants released to the atmosphere are those from the combustion of 11 m^3/yr of diesel fuel. The quantities of fuel combustion products in the air will be well within the limits established by the Federal air quality standards.

Radiological Effects. Since no radioactive materials will be released to the biosphere during planned operation of the indoor unshielded storage facility, there will be no radiological effects.

Ecological Effects. The land (1 ha for case B) occupied by the facility and access road will be unavailable for wildlife production, agriculture, or other uses during the life of the facility. The removal of this small land area from its present use is not expected to be of ecological significance.

8.4.2.3 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with the indoor unshielded storage for low-level transuranic wastes are postulated to lead to releases of radioactive material. A scenario for each accident is provided in DOE/ET-0028.[1] The accidents are listed below.

Accident Number	Description
5.3.1	Mechanical breach of barrel
5.3.2	Dislodging of surface contamination
5.3.3	Overpressurized container
5.3.4	Rusting of steel container
5.3.5	Fire in storage rack

Based on anticipated releases of these minor accidents weighted by their expected frequency of occurrence, an average annual release of radioactive material was determined. The material released is equivalent to 2.5×10^{-5} of 1-year-old waste in 0.5 barrel breaches of low-level transuranic waste. The radionuclides released are given in Table 8.4.2-3.

The 70-year cumulative dose to the maximum individual was calculated and is given in Table 8.4.2-4. Numerically, the largest doses received are a small fraction of the 70-year dose received from naturally occurring sources.

No moderate or severe accidents are postulated for the indoor unshielded storage facility.

TABLE 8.4.2-3. Radionuclides Released to the Atmosphere from Minor Accidents at the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes

Radionuclide	Release, Ci
^{238}Pu	1.1×10^{-4}
^{239}Pu	7.8×10^{-6}
^{240}Pu	1.6×10^{-5}
^{241}Pu	3.5×10^{-3}
^{241}Am	2.9×10^{-5}

TABLE 8.4.2-4. Seventy-Year Dose Commitment to the Maximum Individual from Minor Accidents at the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}
Inhalation	2.1×10^{-4}		1.1×10^{-3}	4.4×10^{-3}
Ingestion	3.5×10^{-8}			1.2×10^{-6}
Total	2.1×10^{-4}	1.1×10^{-11}	1.1×10^{-3}	4.4×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 1100 m north of the site center with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.9×10^{-6} sec/m^3.

REFERENCE FOR SECTION 8.4.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

8.4.3 Comparison of Alternatives for Interim Retrievable Waste Storage of Low-Level Transuranic Wastes

The quantities of resources required for construction of the outdoor surface storage facility and the indoor unshielded storage facility for low-level transuranic wastes are compared in Table 8.4.3-1; resources needed for operation of these facilities are listed in Table 8.4.3-2. For construction, the indoor facility requires more water, materials, energy, and manpower than those required by the outdoor facility. Only in land use do the requirements of the outdoor facility exceed those of the indoor storage. The operational resource requirements for the two storage alternatives are similar.

No radioactive materials will be released during normal operation of either the outdoor or indoor storage facilities. Similarly, no liquid effluents will be released to the environment. Air pollution from the combustion of petroleum products is greater during the construction of the indoor facility. However, the quantities released for either facility are small and of little environmental consequence.

TABLE 8.4.3-1. Summary of the Resources Committed for the Construction of Interim Retrievable Storage Facilities for Low-Level Transuranic Wastes

Resource	Outdoor Surface Storage: Case A (1990)[a]	Outdoor Surface Storage: Case B (1995)[b]	Indoor Unshielded Storage: Case A (1990)[a]	Indoor Unshielded Storage: Case B (1995)[b]
Land, m^2	1.6×10^4	3.2×10^4	5.3×10^3	1.0×10^4
Water, m^3	6.5×10^3	1.3×10^3	3.1×10^3	6.2×10^3
Materials				
Steel, MT	2.3×10^2	4.6×10^2	4.6×10^2	9.3×10^2
Copper, MT	6.5	1.3×10^1	--	--
Lumber, m^3	6.5×10^1	1.3×10^2	7.7×10^1	1.6×10^2
Concrete, m^3	4.9×10^2	9.8×10^2	3.9×10^3	7.8×10^3
Energy				
Propane, m^3	4.6	9.2	3.1×10^1	6.2×10^1
Diesel fuel, m^3	4.6×10^1	9.1×10^1	3.1×10^2	6.2×10^2
Gasoline, m^3	3.3×10^1	6.5×10^1	1.6×10^2	3.1×10^2
Electricity, kWh	negligible	negligible	1.6×10^5	3.1×10^5
Manpower, man-yr	2.9×10^1	5.8×10^1	9.5×10^1	2.0×10^2

a. Case A is based on the cumulative number of drums of waste (65,000) generated by all fuel reprocessing plants and mixed-oxide fuel fabrication plants through the year 1990.
b. Case B is based on the number of drums of waste (130,000) generated through the year 1995.

TABLE 8.4.3-2. Summary of the Average Annual Resource Commitments for the Operation of Interim Retrievable Storage Facilities for Low-Level Transuranic Wastes

Resource	Outdoor Surface Storage: Case A (1990)[a]	Outdoor Surface Storage: Case B (1995)[b]	Indoor Unshielded Storage: Case A (1990)[a]	Indoor Unshielded Storage: Case B (1995)[b]
Materials, m^3				
Plywood (1/2 in.)	3.4×10^3	4.7×10^3	4.6×10^3	6.5×10^3
Plastic sheet	2.1×10^3	3.0×10^3		
Energy				
Diesel fuel, m^3	1.5×10^1	2.3×10^1	7.6	1.1×10^1
Electricity, MWh	2.3×10^5	3.2×10^5	2.3×10^5	3.2×10^5
Manpower, man-yr	3.2	4.3	3.2	4.3

a. Case A is based on the cumulative number of drums of waste (65,000) generated by all fuel reprocessing plants and mixed-oxide fuel fabrication plants through the year 1990.
b. Case B is based on the number of drums of waste (130,000) generated through the year 1995.

No moderate accidents are postulated for the indoor facility. For the outdoor facility, the most serious postulated moderate accident is a tornado strike causing rupture of waste drums and environmental release of radioactive materials. The 70-year dose commitment from this accident is small, less than 0.1% of the dose received from naturally occurring radiation sources over the same period.

The effects resulting from use of any of the fuel cycle options are the same for both the outdoor and indoor storage facilities. For the uranium only recycle option with plutonium stored at an independent storage facility, no mixed-oxide fuel fabrication plant will be required; therefore, the volume of low-level transuranic wastes sent to the independent interim storage facility will be reduced. The effects of the uranium only recycle option with plutonium in solidified high-level waste should be similar.

8.5 COMBINED EFFECTS OF REFERENCE INDEPENDENT RETRIEVABLE WASTE STORAGE FACILITIES

8.5 COMBINED EFFECTS OF REFERENCE INDEPENDENT RETRIEVABLE WASTE STORAGE FACILITIES

Four reference interim waste storage facilities are located at the independent interim retrievable waste storage site. They are 1) sealed storage cask for storage of solidified high-level wastes, 2) subsurface storage of fuel residues, 3) indoor shielded subsurface storage of intermediate-level transuranic wastes, and 4) outdoor surface storage of low-level transuranic wastes. A fifth interim retrievable storage facility is the plutonium oxide storage facility. This facility will be located separately from the others and is discussed in Section 8.6. The plutonium oxide storage facility will not be included in the following discussion of environmental effects. For three of the storage facilities (fuel residues, intermediate-level transuranic wastes, and low-level transuranic wastes) storage of cumulative wastes through 1990 and through 1995 are discussed in Sections 8.2.2, 8.3.1, and 8.4.1. Only the maximum capacity facilities (cumulative storage through 1995) are considered in this section.

8.5.1 Environmental Effects Related to Facility Construction

The four independent interim waste storage facilities will be located on a site of approximately 800 ha. About 170 ha of this area will be occupied by buildings and storage areas and an additional 10 ha will be needed for construction work yards, storage, parking, and temporary buildings.

A 1.6-km two-lane road will be constructed to provide automobile and truck access from the construction site to an existing highway. A 3.2-km railroad spur line will also be built for rail access. The new railroad spur and road will occupy about 6 ha. Several of the facilities will be developed over an extended period of time as more storage modules are added to accommodate more waste. Construction of the sealed storage cask facility for storing solidified high-level waste is expected to extend through the year 2000.

8.5.1.1 Resource Commitments

Total water used during construction of the reference facilities will be about 3.1×10^5 m^3. Other resource commitments are given in Table 8.5.1-1.

8.5.1.2 Physical and Chemical Effects

Nonradioactive pollutants that are released to the air during the reference facility construction result from combustion of equipment and vehicle fuels, fugitive dust from clearing and excavation of land, and particulates from concrete batch plant operation. Amounts of these emissions are given in Table 8.5.1-2; the total amounts listed will be released over a 15- to 20-year period. These values are estimates for the entire construction period. Uncertainties in the rate of construction of the modular facilities make estimates of annual emissions uncertain. It is estimated, however, that annual releases from construction of the waste storage facilities will be less than those from construction of the fuel reprocessing plant, which were small relative to limits specified by Federal air quality standards.

TABLE 8.5.1-1. Materials and Utilities Required for Construction of the Independent Retrievable Waste Storage Facilities

Resource	Use
Materials	
Steel, MT	5.5×10^4
Copper, MT	3.0×10^2
Lead, MT	3.2×10^2
Aluminum, MT	1.8×10^2
Lumber, m^3	1.3×10^4
Concrete, m^3	2.6×10^5
Energy	
Propane, m^3	3.5×10^3
Diesel fuel, m^3	3.5×10^4
Gasoline, m^3	2.5×10^4
Electricity, MWh	
Total consumption	1.7×10^4
Manpower, man-yr	5.1×10^3

TABLE 8.5.1-2. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Independent Retrievable Waste Storage Facilities

Pollutant	Construction Equipment Emissions, MT	Labor Force Vehicle Emissions, MT
Carbon monoxide	1.8×10^4	2.4×10^4
Hydrocarbons	7.3×10^2	3.7×10^3
Nitrogen oxides	2.2×10^3	2.2×10^3
Sulfur dioxide	1.3×10^2	
Particulates	7.2×10^3	

8.5.1.3 Ecological Effects

Construction of the reference facilities will remove about 220 ha from other land use including wildlife habitat. Noise, dust, and human activity will also displace some birds and mammals from the adjacent areas during construction. Soil erosion from cleared land and facility berm construction may cause erosion problems and the removal of silt to adjacent land or surface waters. This will be limited by ditching, paving of cleared areas, and contouring of land. The construction impacts to terrestrial plant and animal life will be confined mainly to the 800-ha site and are not expected to severely affect adjoining areas.

Total estimated water use is 3.1×10^5 m^3 and will extend over the several years of construction. This water will be supplied from the R River at the reference environment (Appendix A), from wells, or from a combination of the two sources. If this total volume of water is assumed to be withdrawn from the R River during a single year, it would represent less than 0.2% and 0.01% of the minimum and mean annual river flows respectively. Removal of this

volume of water from the river would not adversely affect the stream biota or interfere with other river uses. Water intake structures would need to be properly screened to limit the numbers of aquatic organisms removed from the river with the facility construction water.

The air pollutants arising from construction activities are estimated to be within the accepted Federal air quality standards and are not expected to cause a measurable ecological effect.

8.5.2 Environmental Effects Related to Facility Operation

Operation of the reference retrievable waste storage facilities may have an effect on the environment and the natural resources of the surrounding area. The following information is provided to form a basis for evaluating these effects.

8.5.2.1 Resource Commitments

The resources needed for operation of the waste storage facilities are given in Table 8.5.2- This commitment of resources is comparable to that used for a large industrial complex. No unusual impacts are expected from this resource use.

TABLE 8.5.2-1. Materials and Utilities Required for Operation of the Independent Retrievable Waste Storage Facilities

Resource	Average Annual Use
Water, m^3	3.0×10^2
Materials	
Plywood (1/2 in.), m^2	1.0×10^4
Plastic sheet	3.0×10^3
Steel casks, MT	1.2×10^3
Steel shields, MT	1.9×10^3
Steel storage pads, MT	5.0×10^2
Water treatment chemicals, MT	2.1×10^1
Concrete, MT	7.2×10^2
Energy	
Diesel fuel, m^3	7.3×10^2
Electricity, kWh	4.7×10^7
Manpower, man-yr	8.8×10^1

8.5.2.2 Process Effluents

The radionuclides released to the environment come mainly from the sealed storage cask facility for solidified high-level waste. Releases of these radioactive materials are given in Table 8.5.2-2. The radionuclides listed are those that will contribute at least 1% of the total dose to a given organ from any pathway or that are otherwise of interest.

About 2.6×10^9 MJ/yr of heat will be released to the atmosphere by the reference waste storage facilities, with most of this heat (2.5×10^9 MJ/yr) coming from the sealed storage cask facility for solidified high-level waste.

TABLE 8.5.2-2. Radionuclides Released to the Biosphere from the Independent Retrievable Waste Storage Facilities

Radionuclide	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2	U and Pu Recycle
^{90}Sr	1.0×10^{-11}	1.0×10^{-11}	9.7×10^{-12}
^{90}Y		1.0×10^{-11}	
^{125m}Te	4.4×10^{-14}	4.4×10^{-14}	4.8×10^{-14}
^{134}Cs	1.1×10^{-12}	1.1×10^{-12}	1.1×10^{-12}
^{137}Cs	1.5×10^{-11}	1.5×10^{-11}	1.5×10^{-12}
^{154}Eu	7.3×10^{-13}	7.3×10^{-13}	8.1×10^{-13}
^{238}Pu	5.8×10^{-13}		
^{239}Pu	5.8×10^{-14}	2.9×10^{-16}	3.6×10^{-16}
^{240}Pu	9.1×10^{-14}		
^{241}Pu	1.4×10^{-11}		
^{241}Am	3.1×10^{-13}	3.1×10^{-13}	5.4×10^{-13}
^{244}Cm	1.7×10^{-13}	1.7×10^{-13}	1.0×10^{-12}

Air pollutants released to the atmosphere from the combustion of fossil fuels during operation of the reference facilities are shown in Table 8.5.2-3.

TABLE 8.5.2-3. Nonradioactive Pollutants Released During Operation of the Reference Retrievable Waste Storage Facilities

Pollutant	Annual Release, MT	Concentration at Fence-line (1.6 km), $\mu g/m^3$		Federal Air Quality Standard,[a] $\mu g/m^3$
		Maximum	Average	
Hydrocarbons	2.0×10^{-2}	3.0×10^{-3}	2.0×10^{-3}	1.6×10^{2}
Nitrogen oxides	1.0×10^{-1}	6.0×10^{-3}	5.0×10^{-3}	1.0×10^{2}
Carbon monoxide	5.0	3.3	2.2×10^{-1}	4.0×10^{4}
Sulfur oxides	5.0×10^{-2}	3.0×10^{-4}	2.0×10^{-4}	8.0×10^{1}
Particulates	2.0×10^{-1}	2.0×10^{-3}	1.0×10^{-3}	7.5×10^{1}

a. Source: A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

8.5.2.3 Physical, Chemical, and Thermal Effects

Heat will be the major environmental pollutant released at the reference retrievable waste storage facilities. Considering the rejected heat as a passive pollutant, the estimated temperature change at the site fenceline (1.6 km) will be about 1°C at full heat load. At distances of 2 to 3 km the temperature rise will be less than 0.6°C and at 5 km the increase will be about 0.2°C. In comparison, a 2°C change in air temperature is about what would be expected around a town of 1000 population. The release of heat from the reference retrievable waste storage facilities is not considered to be of significance to the environment.

Dust and pollutants from the combustion of fossil fuels will be discharged to the atmosphere. The low concentrations of these pollutants relative to Federal air quality standard limits is reason to expect no environmental damage from their release.

8.5.2.4 *Radiological Effects*

The calculated radiation doses to individuals in the vicinity of the reference facilities are based on the radionuclides listed in Table 8.5.2-2; exposure pathways, demography, and other parameters described for the reference environment (Appendix A); and mathematical models relating dose to man from radionuclide releases (Appendix B). There are no planned releases of radionuclides to ground or water from the reference facilities; the only exposure to man is via airborne effluents.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 8.5.2-4. For comparison, the dose to an individual from naturally occurring sources is about 0.1 rem/yr.

TABLE 8.5.2-4. Annual Doses to the Maximum Individual from Gaseous Effluents Released During Normal Operation of the Independent Retrievable Waste Storage Facilities (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	2.5×10^{-19}	2.5×10^{-19}	2.5×10^{-19}	2.5×10^{-19}	2.5×10^{-19}
Inhalation	1.6×10^{-16}		4.6×10^{-19}	1.5×10^{-14}	2.2×10^{-15}
Ingestion	5.1×10^{-15}	0	4.7×10^{-21}	7.0×10^{-16}	6.3×10^{-15}
Total	5.7×10^{-15}	2.5×10^{-19}	7.1×10^{-19}	1.5×10^{-14}	8.5×10^{-15}
		U Recycle, Pu Stored as PuO_2			
Air submersion	2.5×10^{-19}	2.5×10^{-19}	2.5×10^{-19}	2.5×10^{-19}	2.5×10^{-19}
Inhalation	8.8×10^{-17}		4.6×10^{-19}	1.0×10^{-14}	5.9×10^{-16}
Ingestion	5.2×10^{-15}	0	4.7×10^{-21}	7.0×10^{-16}	6.5×10^{-15}
Total	5.2×10^{-15}	2.5×10^{-19}	7.1×10^{-19}	1.0×10^{-14}	7.1×10^{-15}
		U and Pu Recycle			
Air submersion	2.6×10^{-19}	2.6×10^{-19}	2.6×10^{-19}	2.6×10^{-19}	2.6×10^{-19}
Inhalation	1.5×10^{-16}		5.0×10^{-19}	1.7×10^{-14}	1.5×10^{-15}
Ingestion	5.1×10^{-15}	0	5.1×10^{-21}	7.0×10^{-16}	6.2×10^{-15}
Total	5.3×10^{-15}	2.6×10^{-19}	7.6×10^{-19}	1.8×10^{-14}	7.7×10^{-15}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.

b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the facility was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 8.5.2-5 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 5.5×10^{-7} man-rem received from process sources as given in Table 8.5.2-5.

TABLE 8.5.2-5. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released During Normal Operation of the Retrievable Waste Storage Facilities (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	1.8×10^{-14}	1.8×10^{-14}	1.8×10^{-14}	1.8×10^{-14}
Inhalation	1.1×10^{-11}	3.3×10^{-14}	1.1×10^{-9}	1.6×10^{-10}
Ingestion	2.9×10^{-10}	1.3×10^{-16}	4.2×10^{-11}	3.1×10^{-10}
Total	3.0×10^{-10}	5.1×10^{-14}	1.1×10^{-9}	4.7×10^{-10}
	U Recycle, Pu Stored as PuO_2			
Air submersion	1.8×10^{-14}	1.8×10^{-14}	1.8×10^{-14}	1.8×10^{-14}
Inhalation	6.3×10^{-12}	3.3×10^{-14}	7.2×10^{-10}	4.2×10^{-11}
Ingestion	2.9×10^{-10}	1.3×10^{-16}	4.2×10^{-11}	3.2×10^{-10}
Total	2.9×10^{-10}	5.1×10^{-14}	7.6×10^{-10}	3.6×10^{-10}
	U and Pu Recycle			
Air submersion	1.9×10^{-14}	1.9×10^{-14}	1.9×10^{-14}	1.9×10^{-14}
Inhalation	1.1×10^{-11}	3.6×10^{-14}	1.2×10^{-9}	1.1×10^{-10}
Ingestion	2.9×10^{-10}	1.4×10^{-16}	4.2×10^{-11}	3.1×10^{-10}
Total	3.0×10^{-10}	5.5×10^{-14}	1.2×10^{-9}	4.2×10^{-10}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the sealed storage cask facility for solidified high-level waste was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 220 man-rem. Table 8.5.2-6 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 8.5.2-7 and 8.5.2-8 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 8.5.2-9. The population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with 2.3×10^{-4} man-rem received from the reference facility.

TABLE 8.5.2-6. Summary of Annual Total-Body Doses Received from Operation of the Independent Retrievable Waste Storage Facilities and from Naturally Occurring Sources

	Dose, man-rem
Retrievable waste storage facilities	
Process work force	220
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

TABLE 8.5.2-7. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released During Normal Operation of the Independent Retrievable Waste Storage Facilities (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	7.6×10^{-18}	7.6×10^{-18}	7.6×10^{-18}	7.6×10^{-18}
Inhalation	8.8×10^{-14}	1.4×10^{-17}	4.7×10^{-13}	1.4×10^{-12}
Ingestion	4.2×10^{-13}	1.5×10^{-19}	7.9×10^{-16}	1.7×10^{-12}
Total	5.1×10^{-13}	2.2×10^{-17}	4.7×10^{-13}	3.1×10^{-12}
	U Recycle, Pu Stored as PuO_2			
Air submersion	7.6×10^{-18}	7.6×10^{-18}	7.6×10^{-18}	7.6×10^{-18}
Inhalation	4.0×10^{-14}	1.4×10^{-17}	2.1×10^{-13}	3.6×10^{-13}
Ingestion	4.6×10^{-13}	1.8×10^{-19}	7.9×10^{-16}	1.8×10^{-12}
Total	5.0×10^{-13}	2.2×10^{-17}	2.1×10^{-13}	2.2×10^{-12}
	U and Pu Recycle			
Air submersion	7.8×10^{-18}	7.8×10^{-18}	7.8×10^{-18}	7.8×10^{-18}
Inhalation	7.0×10^{-14}	1.5×10^{-17}	5.9×10^{-13}	8.4×10^{-13}
Ingestion	4.0×10^{-13}	1.6×10^{-19}	7.9×10^{-16}	1.6×10^{-12}
Total	4.7×10^{-13}	2.3×10^{-17}	5.9×10^{-13}	2.4×10^{-12}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. On that basis, no health effects could be expected from doses to the population from the operation of the independent retrievable waste storage facilities.

TABLE 8.5.2-8. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released During Normal Operation of the Independent Retrievable Waste Storage Facilities (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
		U Recycle, Pu in SHLW		
Air submersion	5.5×10^{-13}	5.5×10^{-13}	5.5×10^{-13}	5.5×10^{-13}
Inhalation	6.3×10^{-9}	9.9×10^{-13}	3.4×10^{-8}	9.9×10^{-8}
Ingestion	1.1×10^{-8}	4.5×10^{-15}	2.7×10^{-11}	4.5×10^{-8}
Total	1.7×10^{-8}	1.5×10^{-12}	3.4×10^{-8}	1.4×10^{-7}
		U Recycle, Pu Stored as PuO_2		
Air submersion	5.5×10^{-13}	5.5×10^{-13}	5.5×10^{-13}	5.5×10^{-13}
Inhalation	2.9×10^{-9}	9.9×10^{-13}	1.5×10^{-8}	2.6×10^{-8}
Ingestion	1.2×10^{-8}	4.5×10^{-15}	2.7×10^{-11}	4.9×10^{-8}
Total	1.5×10^{-8}	1.6×10^{-12}	1.5×10^{-8}	7.5×10^{-8}
		U and Pu Recycle		
Air submersion	5.6×10^{-13}	5.6×10^{-13}	5.6×10^{-13}	5.6×10^{-13}
Inhalation	5.0×10^{-9}	1.1×10^{-12}	4.2×10^{-8}	6.0×10^{-8}
Ingestion	1.1×10^{-8}	4.9×10^{-15}	2.7×10^{-11}	4.4×10^{-8}
Total	1.6×10^{-8}	1.7×10^{-12}	4.2×10^{-8}	1.0×10^{-7}

TABLE 8.5.2-9. Summary of 70-Year Total-Body Doses Received from Operation of the Independent Retrievable Waste Storage Facilities and from Naturally Occurring Sources

	Dose, man-rem
Retrievable waste storage facilities	
Process work force (30 yr)	3,600
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

8.5.2.5 Ecological Effects

The release of about 2.6×10^9 MJ/yr of heat to the atmosphere from the retrievable waste storage facilities and the emission of dust and fossil fuel combustion products are not judged to have a significant ecological effect. The added heat, at full facility load, will raise the temperature at the fenceline only about 1°C. The air pollutant concentrations at the fenceline are far below Federal air quality standards limits.

About 3.0×10^5 m^3 of water will be withdrawn from the R River to supply the storage facilities. This is less than 0.005% of the average annual river flow, and removal of this volume of water from the river will not produce a perceptible ecological effect.

Of the total 800 ha set aside for the retrievable waste storage facilities only about 210 ha will be occupied by structures and waste storage areas. The remaining land will be limited to public access and will thus provide relatively undisturbed wildlife habitat.

The estimated capacity of some of the retention ponds appears to be insufficient to hold the calculated runoff from the maximum postulated single 24-hr rainfall. These ponds will need to have the necessary capacity to retain all runoff to minimize ecological damage and to control the spread of radioactive materials.

8.5.3 Environmental Effects Related to Postulated Accidents

No severe accidents are postulated for the reference retrievable waste storage facilities. The postulated moderate accident that will release the greatest quantities of radioactive materials (Accident 5.2.1 in DOE/ET-0028[1]) is the breach of a zirconium waste canister by dropping. For this accident, which is also discussed in Section 8.2.1, it is assumed that a canister containing 1320 kg of zirconium waste is breached, exposing 0.14 of the contained metal to the atmosphere. About 5.4×10^{-4} of the exposed material is entrained in the atmosphere. A ground release period of 1 hr and a 1.5-year storage decay time out of the reactor is assumed. The estimated frequency of this accident is 0.2 per year. The radioactive material released by such an event is given in Table 8.2.1-3.

The calculated 70-year dose commitment to the maximum individual is presented in Table 8.5.3-1. The largest of these values is less than 5% of the dose the individual would have received from naturally occurring sources during the period.

TABLE 8.5.3-1. 70-Year Dose Commitment to the Maximum Individual Resulting from a Moderate Accident at the Independent Retrievable Waste Storage Facilities

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle Only			
Air submersion	1.1×10^{-5}	6.4×10^{-6}	6.4×10^{-6}	6.4×10^{-6}	6.4×10^{-6}
Inhalation		1.2×10^{-2}	1.8×10^{-5}	1.1×10^{-1}	2.1×10^{-1}
Total	1.1×10^{-5}	1.2×10^{-2}	2.4×10^{-5}	1.1×10^{-1}	2.1×10^{-1}
		U and Pu Recycle			
Air submersion	1.1×10^{-5}	6.4×10^{-6}	6.4×10^{-6}	6.4×10^{-6}	6.4×10^{-6}
Inhalation		7.2×10^{-3}	1.7×10^{-5}	5.7×10^{-2}	1.1×10^{-1}
Total	1.1×10^{-5}	7.2×10^{-3}	2.3×10^{-5}	5.7×10^{-2}	1.1×10^{-1}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the site center with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.7×10^{-4} sec/m^3.

8.5.4 Decommissioning Considerations

The reference retrievable waste storage facilities have varying expected useful lives. The sealed storage cask facility for solidified high-level waste is designed for a useful operating life of 100 years. Plans for decommissioning must provide for appropriate decontamination equipment and systems and for monitoring and recording equipment to assess contamination levels. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination will be covered with a removable surface before placement of wastes.

8.5.5 Socioeconomic Impacts of Construction and Operation of a Retrievable Waste Storage Facility

Socioeconomic impacts associated with construction and operation of a retrievable waste storage facility depend largely on the numbers of persons who move into the county in which the facility will be located.* Because of this, the size of the local population influx was forecasted and estimates of their need for locally provided social services were determined.

Specific economic impacts attributed to the development of these facilities will not be treated here because they are too dependent on local site characteristics to allow for generalization.

Socioeconomic impacts also depend on site characteristics (Appendix C) and the assumptions used in the forecasting model. Site characteristics that are especially important in influencing the size of the impacts forecasted include the availability of the local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (population size, degree of urbanization, etc.) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible and they differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts.

The socioeconomic model used in this analysis forecasts a regional population in five-year intervals in the absence of any project activities. This population forecast serves both as a comparative baseline and as a source for a portion of the postulated future project employment. The model takes account of both primary and secondary employment effects (such as additional retail store clerks) and incorporates as separate components spouses of members of the labor force and other dependents. Regional migrants associated with the project are

* The manpower required to construct and operate a waste storage facility is estimated at a mean level of 1060 man-yr per yr during construction (1980-1984) and 164 man-yr per yr during operations (1985-2015). Since some construction activities may extend into the operations phase (through 1995), impact forecasts for the 1985 period may be somewhat low. This is discussed further in the text.

distributed residentially to counties throughout the commuting region. The model accounts for separation and retirement from project employment and replacement by a new labor force. It also specifies the tendency of workers and their dependents to leave the region upon job completion.

In the following analysis, impacts are presented in terms of an expected level of impact and in terms of a maximum level of impact. The expected impact condition is based on the most likely value of model assumption, whereas the maximum impact condition places an extreme but credible value on the model assumptions. Table 8.5.5-1 presents estimates of the cumulative project-related in-migrants for the facilities for the three reference sites over time. The forecasted values include primary and secondary employment and associated household dependents. All are in-migrants, since impacts are assumed to be generated primarily by new in-migrants. Over time, some of the persons who separate from the facility will stay in the site county and some will leave. Those who stay are contained in the forecasted values until they leave the area. Thus, not all the forecasted populations are actually working on or directly associated with the project at the time indicated. Nevertheless, the presence of each of these persons was determined by the existence of the project, and they would not likely be present if the project had not occurred. The percentages associated with each population in these tables reflect the size of the in-migrant group relative to the baseline population in the respective sites. Since these baseline populations vary by site, the relative impact of a similar in-migrant group can vary greatly.

TABLE 8.5.5-1. Forecasts of Population Influx for a Retrievable Waste Storage Facility (number of persons)

Site	1980	1985	2000	2015
		Expected Impact Condition		
Southeast	156 (0.07%)	149 (0.6%)	174 (0.7%)	174 (0.7%)
Midwest	31 (0.1%)	268 (0.4%)	313 (0.3%)	353 (0.4%)
Southwest	3196 (6.7%)	1832 (3.8%)	2206 (4.2%)	2387 (4.2%)
		Maximum Impact Condition		
Southeast	2201 (9.4%)	1527 (6.2%)	1827 (6.5%)	1981 (6.5%)
Midwest	666 (1.1%)	947 (1.3%)	1125 (1.2%)	1268 (1.3%)
Southwest	4865 (9.9%)	2868 (5.9%)	3460 (6.4%)	3735 (6.4%)

Note: Numbers in parentheses denote percentage of the population influx based on the baseline population.

The expected soeioeconomic impacts of the retrievable waste storage facilities in the Southeast and Midwest sites are judged to be insignificant. The total numbers of forecasted new in-migrants do not even reach 1% of the baseline population in the construction (1980-1986) and operations phases (1985-2015). In addition, there are no very large transitions over time.

The effect of the project is substantially different in the Southwest site. The number of in-migrants during construction is more than three times the level of primary employment demand (3,196 versus 1,060). As a percent of project baseline population size, the potential for significant impacts is much greater in the Southwest. There is a substantial drop in the size of the in-migrant population over the transition from construction to operations. This decline in population influx of more than 40% sets the stage for a boom and bust type of effect in the Southwest reference site. Since it is likely that construction will actually last longer than the five-year construction period assumed in this analysis, the drop in the project related population in 1985 may not actually occur until 1995.

The maximum impact condition for the retrievable waste storage facility produces substantially larger project-induced in-migrant flow for each site compared with the expected condition. Maximum impacts associated with the retrievable waste storage facility in the Southwest reference site are the largest obtained for the facility. The transition from construction to operation produces the same relative decline as was found under expected conditions but at a higher absolute level. This is reflected in the larger relative (to baseline) impacts (for example, 9.9% versus 6.7% in the Southwest case).

Translating forecasted project-related in-migration into socioeconomic impacts is complex and imprecise. Estimates of the level of demand that will be placed on the community to provide social services to the new workers and their families were made by applying a set of factors (Appendix C) to the project in-migration values. The product of these factors indicates how many units of each social service would be "expected" by the in-migrants. The significance of the impacts is primarily related to the capacity of the site county to meet these expectations.

The calculated levels of likely and maximum social service demands at the three reference sites are given in Table 8.5.5-2 for the year 2000.

8.5.6 Commentary on Environmental Effects Associated with Operation of Combined Facilities at the Independent Retrievable Waste Storage Facility

The reference retrievable waste storage facility provides sealed cask storage for up to 100 years for solidified high-level wastes, fuel residues, and intermediate- and low-level transuranic wastes. This interim storage is a contingency design against the near-term unavailability of deep geologic or other suitable method for isolation of these wastes from the biosphere for substantially all time.

Actual predicted adverse environmental effects related to this complex of storage facilities are inconsequential. Although about 800 ha will be removed from present use only about one-fourth of this area will be needed for storage structures and related support facilities. As a consequence, about 600 ha will be available for protected terrestrial habitat. Modern construction practices coupled with stringent regulations all but preclude deleterious effects on aquatic ecosystems. The natural resources used for construction and operation of these facilities do not appear to be disproportionately large. It is believed that the retrievable waste storage facility could be built and operated without significant effects on the environment.

TABLE 8.5.5-2. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Retrievable Waste Storage Facility.

Selected Social Services	Year 2000					
	Expected Demand			Maximum Demand		
	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	0	0	2	2	2	3
Nurses	1	2	6	5	6	9
Dentists	0	0	1	1	1	1
Hospital beds	1	2	7	7	7	12
Nursing care beds	0	2	5	3	6	7
Education						
Teachers (K-12)	2	4	28	23	12	45
Classroom space, m^2 (9-12)	270	530	3390	2760	1560	5270
Sanitation, m^3/day						
Water treatment	100	180	1250	1040	640	1960
Liquid waste	70	120	840	690	430	1310
Safety						
Firemen	0	0	2	1	1	2
Policemen	0	1	4	4	2	7
Recreation, ha						
Neighborhood parks	0	0	2	2	1	3
Government						
Administrative staff	0	0	2	2	1	3
Other social impacts						
Crimes (7 crime index)	8	14	129	55	48	202

A subjective hazard associated with operation of the retrievable waste storage facility, however, involves the containment of radioactive material in the event of man-made or natural disruptive disasters. Thus, the concept of deep geologic isolation of solidified high-level waste and other long-lived wastes is being vigorously pursued for this reason. All of the accidents that could take place with extremely low probabilities in deep geologic repositories could conceptually occur with greater probability with wastes on the surface. For the retrievable waste storage facility, the reference containment of solidified high-level waste is in welded steel containers contained in massive concrete storage casks. Breach of these casks by means other than direct impact of very large meteorites or nearby explosions of a nuclear weapon is not believed to be credible; breach by tornado or earthquake is virtually impossible. Moreover, other effects associated with the initiating event are believed to be vastly more serious than the release of stored radioactive material. Containment of solidified high-level waste is of principal interest and substantial redundancy has been built into the storage structure. Fuel residues are substantially as impregnable. Transuranic waste does not require the same degree of assurance of containment as solidified high-level waste because of the

difficulty with which sufficient quantities of these wastes can interact with the biosphere. Tornadoes may rupture 55-gal drums and thus dispense their contents. However, during storage of drums such an event was shown to be insignificant.

Although the retrievable waste storage facility is not meant to stand against the effects occurring over geologic time, it is believed that such a facility is an environmentally satisfactory interim measure in the event deep geologic or other isolation of reprocessing wastes is not available as scheduled.

8.6 INTERIM RETRIEVABLE STORAGE OF PLUTONIUM OXIDE

8.6 INTERIM RETRIEVABLE STORAGE OF PLUTONIUM OXIDE

In the event spent fuel reprocessing for recycle of uranium alone should prove acceptable and attractive, interim storage of large quantities of plutonium might be necessary until a permanent solution to the use or disposal of plutonium could be defined. Storage of plutonium in the form of a plutonium compound (separate from fission products and other waste products) would afford ease of retrieval should recycle of plutonium as a fuel be adopted in the future. Currently there are no plans to place plutonium oxide separately in deep geologic repositories. (Plutonium may be in the oxide form in solidified high-level waste.)

8.6.1 Independent Interim Plutonium Oxide Storage Facility

The independent interim plutonium oxide storage concept involves a vault type of structure that will house a concrete storage slab in the floor of the vault. Steel-lined holes will house containers specifically designed to store plutonium oxide. The facility will provide nuclear criticality control, radioactive decay heat removal, radiation shielding, and protection against diversion or theft of the plutonium.

Each storage container holds a 32-kg nominal loading. The storage container also serves as the pressure vessel of the transport container. A flow diagram of the operation of the interim plutonium oxide storage facility is shown in Figure 8.6.1-1. The arrows indicate the path for placing a storage container in the storage slab. Removal of the container is a reverse operation. Each interim plutonium oxide storage facility is designed to handle 8 to 10 containers of plutonium oxide (320 kg) in 24 hr; the facility will accommodate 200 MT of plutonium oxide.

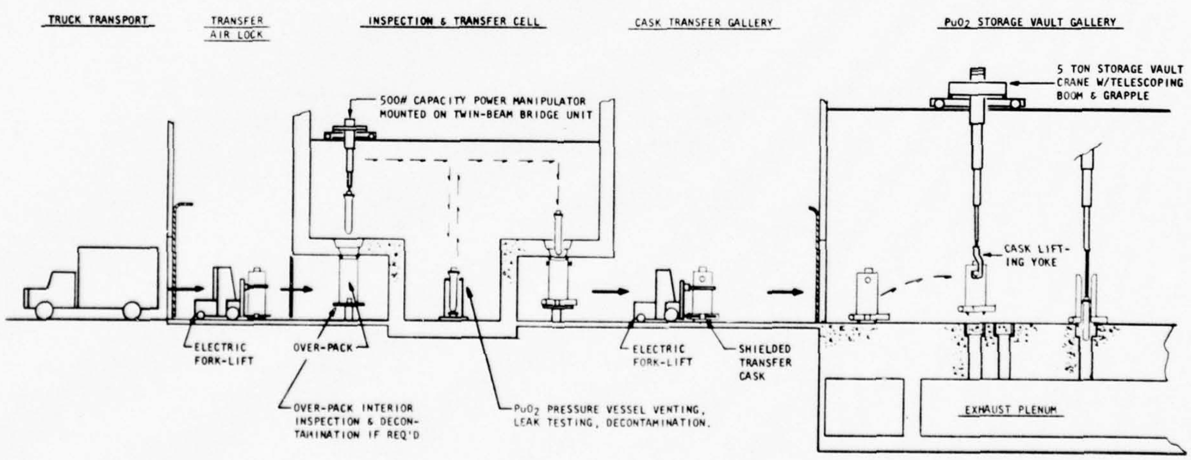


FIGURE 8.6.1-1. Flow Diagram for Interim Plutonium Oxide Storage Facility

Air cooling will be used to remove the heat generated by the plutonium product in the storage containers. Air flow will be from the storage vault down through the annulus between the sleeve and the pressure vessel to an exhaust plenum located below the storage slab. The exhaust plenum will be divided by load-bearing walls that divide the air flow into separately monitored air ducts. The exhaust plenum will have a minimum floor-to-ceiling height of 1.8 m to allow entrance for decontamination purposes. After filtration, the cooling air will be discharged to the atmosphere through an exhaust stack 100 m high.

The plant site is a tract of about 1000 ha fenced with posted agricultural type of fencing. The main storage facilities are located near the center within a protected security area of about 9 ha. Surrounding the central protected area is a security-monitored strip 30 m wide bordered by security fences at the outer and inner perimeters of the strip.*

8.6.1.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. Land requirements for the independent interim plutonium oxide storage facility include 13 ha for the construction of the facility, plus an additional 32 ha for construction storage, work yards, temporary buildings, and work force parking. A 4.8-km two-lane paved access road will be required. Although the amount of land needed for the storage facility site is large (1000 ha), it has no unique siting requirements and site selection should be possible without significantly affecting other land uses.

Water use during the 3-year construction period will be approximately 7.4×10^4 m^3 or about 2.5×10^4 m^3/yr. This water will be supplied from the R River at the reference environment (Appendix A) or from wells located at the site. This quantity of water is small relative to the mean annual flow (3.9×10^9 m^3) of the R River and should not affect other downstream water uses.

Other resources needed for construction of the plutonium oxide storage facility are given in Table 8.6.1-1.

TABLE 8.6.1-1. Materials and Utilities Required for Construction of the Independent Interim Plutonium Oxide Storage Facility

Resource	Use
Steel, MT	1.1×10^4
Copper, MT	1.6×10^2
Zinc, MT	4.5×10^1
Aluminum, MT	3.6×10^1
Lumber, m^3	2.5×10^3
Concrete, m^3	4.7×10^4
Propane, m^3	6.2×10^2
Diesel fuel, m^3	6.2×10^3
Gasoline, m^3	4.1×10^3
Electricity	
Peak demand, kW	1.7×10^3
Total consumption, kWh	3.1×10^6
Manpower, man-yr	2.7×10^3

* Currently being reviewed for safeguards adequacy.

Physical and Chemical Effects. During facility construction, fugitive dust will be generated by grading, excavation, and other activities. It will be controlled by paving, oiling, or surface wetting of the roads and excavation sites.

The combustion products from about 11,000 m^3 of fossil fuels burned by construction equipment will be released to the atmosphere and will increase the air concentrations of hydrocarbons, carbon monoxide, and oxides of sulfur and nitrogen. The concentrations of these air pollutants at the site fenceline will be below the limits specified in Federal air quality standards.

Noise from construction activities will vary from day to day, depending on equipment operation, weather conditions, and other factors. Noise levels will be monitored to ensure compliance with Occupational Safety and Health Act, Environmental Protection Agency, and state standards.

Soil erosion may occur in areas disturbed by construction activities and will be controlled by drainage ditches and contouring of the land. These control measures and the generally level terrain at the site will prevent or limit the movement of soil outside of the 1000-ha site.

Ecological Effects. The total land area of the independent interim plutonium oxide storage facility will be 1000 ha. Approximately 13 ha will be cleared for facility installations and 32 ha will be cleared for construction storage, work yards, temporary buildings, and parking area. In addition, 4.8 km of two-lane paved roads will be constructed to provide vehicle access to the facility. The main storage facilities will be located near the center within a security area of about 9 ha. Surrounding the central security area will be a strip 30 m wide, which also will be enclosed by a security fence.

Wildlife habitat will be destroyed for the life of the facility (50 years or more) within the 13-ha secured area. In the construction storage area, vegetation and animal habitat will be destroyed during construction and for the period necessary to reestablish vegetation after completion of construction. There will also be some disturbance of birds and mammals in the area adjacent to the construction site as a result of dust, noise, and human activity. The construction and heavy travel on the access highway will probably increase the incidence of animal road kills. The construction impacts on the terrestrial ecosystem are judged to be acceptable and similar to other industrial uses of comparable land areas. About 950 ha will be closed to human activities and should provide a substantial addition to the protected terrestrial habitat.

During the 3-year facility construction period, water use will be 7.4×10^4 m^3 or a yearly average of about 2.5×10^4 m^3. This will be supplied from the R River near the reference site and is approximately 0.01% of the minimum 40-year recorded low flow or less than 0.001% of the average flow. Withdrawal of this small fraction of the stream flow will have no measurable effect on the river biota. This water requirement could also be provided by wells without serious depletion of the groundwater.

8.6.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. The resources needed for operation of the independent plutonium oxide storage facility are given in Table 8.6.1-2.

TABLE 8.6.1-2. Annual Materials and Utilities Required for Operation of the Interim Independent Plutonium Oxide Storage Facility

Resource	Average Annual Use
Water consumed, m^3	1.6×10^5
Oil, m^3	2.3×10^2
Electricity, kWh	2.9×10^7
Manpower, man-yr	6.1×10^1

Process Effluents. During planned operation of the facility, no radioactive pollutants will be released to air, water, or ground.

During storage of plutonium oxide, heat will be generated and transferred to the atmosphere by natural convection. A cooling tower to provide heat exchange for chilling ventilation air will release about 1.7×10^3 m^3/yr in blowdown. About 9.7×10^4 m^3/yr will be evaporated and about 4.9×10^2 m^3/yr will occur in drift. About 2.1×10^8 MJ/yr of waste heat will be released.

There will be no planned releases of nonradioactive material to the land or water from the facility.

Physical, Chemical, and Thermal Effects. The release of about 2.1×10^8 MJ/yr is about 9% of that released from the fuel reprocessing plant or surface storage of solidified high-level waste. This is approximately the amount of heat released from an urban shopping center and is not expected to have an adverse environmental effect.

Radiological Effects. For normal operation of the storage facility, there are no planned releases of radioactive material to air, water, or ground; therefore there are no pathways for radionuclides to man.

Ecological Effects. During normal facility operation there will be no liquid or gaseous discharges of nonradioactive pollutants. Approximately 2.1×10^8 MJ/yr of heat will be released to the atmosphere, which is not expected to have an ecological effect.

Approximately 1 x 10^5 m^3 of water will be used annually for cooling and sanitary purposes. This water will be supplied from the R River near the reference site. Withdrawal of this volume of water amounts to about 0.003% of the mean annual river flow and should not adversely affect the river ecosystem.

The restricted portion (13 ha) of the independent plutonium oxide storage facility will be unavailable for other uses for the 50 or more years of useful facility life plus the additional period required for decontamination and decommissioning. Much of the 1000-ha site area will not be occupied by the storage facility, but public access to this area will be restricted. Because of this reduction in human disturbance, the usefulness of this area for wildlife habitation will probably be enhanced.

8.6.1.3 Environmental Effects Related to Postulated Accidents

Two minor and two moderate accidents were postulated for the facility. It was concluded that none of these accidents would result in the release of radioactive material to the biosphere. The accident scenarios are described in DOE/ET-0028(1) and are listed below.

Accident Number	Description
	Minor
5.5.1	Loss of normal electrical power
5.5.2	Temporary loss of ventilation blower
	Moderate
5.5.3	Decontamination trash fire
5.5.4	Storage container leakage

Two severe accidents postulated for the plutonium oxide storage facility that could release radioactive materials to the environment are listed below.

Accident Number	Description
5.5.5	Storage container breach
5.5.6	Criticality

For Accident 5.5.5, it was assumed that a breach in one storage container resulted in the release of 200 g of plutonium oxide to the filters over a period of 30 min. The radioactive material associated with such an event is listed in Table 8.6.1-3.

TABLE 8.6.1-3. Radionuclides Released During a Severe Accident at the Independent Interim Plutonium Oxide Storage Facility

Radionuclide	Release, Ci
^{238}Pu	5.2×10^{-11}
^{239}Pu	5.2×10^{-12}
^{240}Pu	8.1×10^{-12}
^{241}Pu	1.2×10^{-9}
^{241}Am	2.2×10^{-11}

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 8.6.1-4. The largest dose was 3.2×10^{-9} rem to the bone via inhalation. This dose is six orders of magnitude less than the nominal 5.0×10^{-3} rem/yr variation in dose received from naturally occurring sources and is not considered significant.

TABLE 8.6.1-4. 70-Year Dose Commitment to the Maximum Individual from a Severe Accident in the Independent Interim Plutonium Oxide Storage Facility (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	8.0×10^{-18}	8.0×10^{-18}	8.0×10^{-18}	8.0×10^{-18}
Inhalation	1.6×10^{-10}		9.4×10^{-10}	3.2×10^{-9}
Total	1.6×10^{-10}	1.3×10^{-17}	9.4×10^{-10}	3.2×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 6.0×10^{-5} sec/m^3.

For Accident 5.5.6, it was assumed that material from a criticality event of 10^{19} fissions was released to the facility filters over a period of 15 min. Approximately 200 g of stored plutonium oxide plus the material listed in Table 8.6.1-5 were released.

TABLE 8.6.1-5. Radionuclides Released to the Biosphere from a Plutonium Criticality Accident in the Independent Interim Plutonium Oxide Storage Facility

Radionuclide	Release, Ci
^{85}Kr	1.6×10^{-3}
^{87}Kr	1.0×10^{3}
^{88}Kr	6.6×10^{2}
^{89}Kr	4.1×10^{4}
^{129}I	4.3×10^{-10}
^{131}I	1.8
^{133}I	3.5×10^{1}
^{134}I	4.8×10^{2}
^{135}I	1.2×10^{2}
^{138}Xe	1.1×10^{4}

As Table 8.6.1-6 shows, the major contribution to all doses resulted from the criticality accident. The 70-year dose commitment to the thyroid of the maximum individual is on the order of the doses received from naturally occurring sources.

TABLE 8.6.1-6. 70-Year Dose Commitment to the Maximum Individual from a Plutonium Criticality Accident in the Independent Interim Plutonium Oxide Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	4.9×10^{-2}	7.5×10^{-2}	7.5×10^{-2}	7.5×10^{-2}	7.5×10^{-2}
Inhalation		3.0×10^{-4}	1.0×10^{-1}	3.2×10^{-3}	9.9×10^{-5}
Total	4.9×10^{-2}	7.5×10^{-2}	1.8×10^{-1}	1.1×10^{-2}	7.5×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 1800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.4×10^{-5} sec/m^3.

No accidents have been identified that would result in the release of ecologically significant nonradioactive pollutants. There will be some storage of diesel and gasoline used for fuel in emergency generators and forklifts. Accidental release of these products is possible from storage tanks or during delivery. However, onsite quantities of these fuels will not be large, and their accidental release will probably be confined to the secured area of the facility.

REFERENCES FOR SECTION 8.6.1

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

8.7 DIFFERENTIAL EFFECTS RELATED TO THE URANIUM AND PLUTONIUM RECYCLE AND THE URANIUM ONLY RECYCLE OPTIONS

8.7 DIFFERENTIAL EFFECTS RELATED TO THE URANIUM AND PLUTONIUM RECYCLE AND THE URANIUM ONLY RECYCLE OPTIONS

In terms of interim storage of reprocessing wastes at the retrievable waste storage facility, there are no significant differences in environmental effects based on the reprocessing option. One exception, however, is if an independent plutonium oxide storage facility is located adjacent to the retrievable waste storage facility. In that case the regional population would be subject to effects from that facility for the option of uranium recycle with plutonium oxide stored. The environmental effects associated with an independent plutonium oxide storage facility are discussed in Section 8.6.

It is also possible that an independent plutonium oxide storage facility would be required under a uranium and plutonium recycle option. The reason involves an expected excess of plutonium for mixed-oxide fueling of light-water reactors in the 1980 to 2050 scenario. While other light-water reactors or breeder reactors may use the excess fuel, there is a point at which recycling of plutonium is no longer feasible because of the "grow-in" of high isotopes such as ^{242}Pu and ^{244}Pu. Since about three recycles of plutonium fuel are necessary to reach that point, it is believed that suitable deep geologic storage of such wastes will have been developed by that time, which will obviate the need for storage of plutonium oxide at a retrievable waste storage facility.

9.0 ENVIRONMENTAL EFFECTS RELATED TO GEOLOGIC ISOLATION OF LIGHT WATER REACTOR FUEL REPROCESSING WASTES

(DOE/ET-0028 Section 7.5)

9.0 ENVIRONMENTAL EFFECTS RELATED TO GEOLOGIC ISOLATION OF LIGHT WATER REACTOR FUEL REPROCESSING WASTES (DOE/ET-0028 SEC. 7.5)

Environmental effects of waste disposal are analyzed for three reprocessing fuel cycles: uranium and plutonium recycle; uranium recycle only, with plutonium in high-level waste; and uranium recycle only, with PuO_2 stored for future use or disposal. Repository construction requirements are substantially the same for the three reprocessing options. Surface facilities and land requirements for disposal of transuranic wastes from reprocessing are similar to those for spent fuel repositories. Geologic formations judged potentially acceptable as waste repository media, and for which conceptual repository descriptions have been developed for this report, are salt, granite, shale, and basalt.

A repository operating in support of any of the reprocessing fuel cycles will receive solidified high-level waste (SHLW), fuel residue wastes (FRW), intermediate-level transuranic wastes (TRU-ILW), and low-level transuranic wastes (TRU-LLW). The characterisitics of wastes produced, projected annual quantities of wastes delivered to the repository, and cumulative amounts of wastes in these fuel cycles are described in DOE/ET-0028, Sec. 3.

Canisters of SHLW, FRW and ILW are received and handled at the repository in the same manner previously described for spent fuel canisters in the once-through fuel cycle repository (see Section 4.4). Intermediate-level waste in 55-gal drums is shipped to the repository by truck, arriving in shielded overpacks.

The overpacks are lifted by crane from the truck bed to shielded transfer cells for remote removal of the drums. The drums are placed three to a steel drum-pack canister, which is sealed with a welded lid. The drum-pack is transported to the canistered waste shaft and lowered into the repository.

Low-level waste arrives at the repository on pallets of twelve 55-gal drums stacked two by three by two drums high, and in steel boxes measuring 1.2 x 1.8 x 1.8 m (4 x 6 x 6 ft), roughly equivalent in size to the pallet of drums. The LLW is shipped by truck, in Supertiger® cargo carriers (see Section 6.6 of DOE/ET-0028). Each carrier is loaded with three pallets or boxes of waste. The pallets and boxes are unloaded from the Supertiger® using shielded forklifts, inspected for damage and repaired if necessary, transported to the low-level waste shaft and lowered into the repository.

Wastes are received at subsurface transfer stations that form integral structures with the shafts. Shielded transporters remotely remove the containers from the transfer stations for delivery to an emplacement area.

At the reference repositories in salt, granite, shale and basalt formations, HLW canisters are lowered into vertical holes in the emplacement rooms. The same minimum-hole spacing is used as that described for spent fuel canisters in the once-through fuel cycle repositories, and an

allowable thermal density is calculated specifically for the HLW's characteristics. In salt and shale, FRW and ILW are also emplaced in holes; however, the minimum center-to-center hole spacing is increased to 2.3 m (7.5 ft) because of the larger hole diameters for these wastes. For repositories in granite and basalt, FRW and ILW canisters are lowered into trenches running the length of the rooms. The canisters are held upright in a single row by storage racks that allow a minimum center-to-center spacing of 1 m (3.5 ft). The LLW, in drums on pallets and in boxes, is stacked two high along the walls of LLW emplacement rooms using shielded forklifts.

The reference repositories for reprocessing wastes are operated with the same initial waste retrieval period as described for the once-through fuel cycle repositories. Steel sleeves and concrete plugs are used as described for the spent fuel to protect the emplaced HLW, FRW and ILW canisters during the retrieval period.

After the retrieval period and once a room is filled to its capacity with wastes, it is backfilled to within 0.6 m (2 ft) of the room ceiling with crushed rock from prior repository mining. Table 9.0-1 lists the contents of reference repositories located in salt, granite, shale and basalt formations at the end of emplacement.

TABLE 9.0-1. Contents of First Repository When Full

		Equivalent MTHM[a]			
Fuel Cycle	Waste	Salt	Granite	Shale	Basalt
Uranium-only recycle, plutonium in HLW					
	SHLW[b]	38,500	69,000	30,500	56,000
	All others	69,000 (1999)[c]	108,500 (2004)	56,000 (1997)	91,500 (2002)
Uranium-only recycle, plutonium stored					
	HLW	76,500	69,000	30,500	56,000
	All others	118,000 (2005)	108,500 (2004)	56,000 (1997)	91,500 (2002)
Uranium and plutonium recycle					
	HLW	62,170	69,000	30,500	56,000
	All others	99,670 (2003)	108,500 (2004)	56,000 (1997)	91,500 (2002)

a. Tonnes of reprocessed heavy metal corresponding to wastes contained in the repository.
b. Equivalent MTHM for SHLW does not correspond to the MTHM for all others because of a 5-yr delay for SHLW cooling between reprocessing and shipment to the repository.
c. Final year of operation assuming 1985 repository startup.

The reference repositories for the reprocessing fuel cycles are excavated on the same 7-yr schedule described for the once-through fuel cycle repositories. Table 9.0-2 compares mining and rock handling requirements for repositories in the four geologies and three reprocessing fuel cycles.

TABLE 9.0-2. Mining and Rock Handling Requirements MT x 10^6

Fuel Cycle	Repository Medium Salt	Granite	Shale	Basalt
Uranium-only recycle, Plutonium in HLW				
Total mined	30	52	30	59
Room backfill	13	16	12	17
Total backfill	17	25	17	27
Permanent onsite storage	13	27	13	32
Uranium-only recycle, PuO_2 stored				
Total mined	36	52	30	57
Room backfill	15	17	12	16
Total backfill	20	24	17	25
Permanent onsite storage	16	28	13	32
Uranium and plutonium recycle				
Total mined	35	53	30	59
Room backfill	15	17	12	17
Total backfill	20	24	17	27
Permanent onsite storage	15	29	13	32

The reference repositories consist of surface facilities for waste receiving and handling, mining support, and general operations support. Subsurface facilities are for waste handling and storage and mined rock removal. The surface facilities and the mined rock storage pile constitute the only visible evidence of the repository and occupy an area of about 180 ha (440 acres) at the salt and shale repositories and 220 ha (540 acres) at the granite and basalt repositories.

Surface facilities at these conceptual repositories are designed to the same criteria and requirements as the once-through fuel cycle repository facilities. However, some wastes (ILW drums and LLW drums and boxes) are shipped by truck to these repositories and require appropriately designed receiving facilities.

The reference repositories for the reprocessing fuel cycles in salt and shale formations require four shafts to support waste handling and mining operations. These are the canistered waste (CW) shaft, the low-level waste (LLW) shaft, the men and materials (M&M) shaft and the ventilation exhaust (VE) shaft. These shafts differ in size, design, use, and function.

The canistered waste shaft provides a means for transporting the canisters of SHLW, FRW and ILW from the canistered waste building to the subsurface emplacement areas. The top of the shaft forms an integral part of the canistered waste building. At mine level, the shaft

provides access to the FRW/ILW receiving station on one elevation and the SHLW receiving station 23 m (75 ft) lower. The receiving stations provide shielded facilities for the remote transfer of canisters from the shaft.

The low-level waste shaft provides for transport of LLW pallets and boxes from the low-level waste building to the subsurface emplacement areas. The shaft forms an integral part of the LLW building on the surface and the LLW receiving station at mine level. The receiving stations provide for shielded transfer of LLW from the shaft.

The men and materials shaft is provided for personnel, and for movement of equipment, ventilation air supply and mined rock during excavation and backfilling. To meet these requirements, the M&M shaft contains a personnel and equipment cage, mined material hoisting skips, a manway and utility access space and two auxilliary compartments for skip counterweights.

The ventilation exhaust shaft is divided into two compartments to provide separate exhaust for mining and placement operations. The shaft discharges into the ventilation exhaust building.

Reference repositories in granite and basalt require the excavation of substantially greater amounts of rock than do the salt and shale repositories. In order to handle the increased rock quantities, a mine production (MP) shaft is required at the granite and basalt repositories in addition to the four shafts previously described. The MP shaft contains skip hoist equipment for removal of mined rock to the surface and supplies additional ventilation air to the mine.

The overall underground area is bounded by an upper limit of 800 ha (2000 acres). This limit is set on the basis of reasonable waste storage capacity and waste transport efficiency. Allocation of the repository's 800 ha to the four types of waste (HLW, FRW, ILW and LLW) varies slightly among the three reprocessing fuel cycles. This variation, owing to the different thermal characteristics of HLW from each of the fuel cycles, does not alter the basic underground design and layout.*

The underground repository is laid out in a conventional room and pillar arrangement that provides repository ventilation, opening stability, heat dissipation and efficient use of excavated space. Of the 800 ha total area, waste emplacement areas occupy 650 to 730 ha (1600 to 1800 acres), with the remaining 70 to 150 ha occupied by shafts, general service areas, main corridors and unmined areas within the repository. Mine areas for HLW and FRW/ILW emplacement are located on different elevations and are offset from each other so that there is no overlap or stacking of emplacement areas.

The reference repository in salt is excavated through the use of continuous mining machines. The resulting emplacment rooms for FRW and ILW are 1000 m (3300 ft) long and extend at right angles directly off the main corridors. The rooms are grouped into panels of four rooms each, with 9-m (3-ft) wide yield pillars of intact rock between rooms. Panels are separated by buttress pillars 24 m (78 ft) wide.

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* Basically, waste placement is a balance of cost of mining against the estimated heat load that the host rock can contain without compromising the integrity of the repository. The reference repositories could have as easily been described in terms of a fixed waste capacity regardless of media, rather than in terms of fixed area.

The SHLW emplacement rooms in a salt formation are excavated to a length of 170 m (560 ft) at right angles off branch corridors. Each room is separated from the next by an 18-m (60-ft) wide pillar of intact rock. The branch corridors extend at right angles off the main corridors.

The conceptual design for repositories in granite, shale and basalt provides for use of conventional drill and blast mining techniques to excavate for all subsurface emplacement areas. In this arrangement, branch corridors are excavated perpendicularly off main corridors that lead from the shafts. Along one wall of each branch corridor, emplacement rooms 170 m (560 ft) long are excavated. Each room is separated from the next by a pillar of intact rock.

9.1 ENVIRONMENTAL EFFECTS RELATED TO FACILITY CONSTRUCTION

9.1 ENVIRONMENTAL EFFECTS RELATED TO FACILITY CONSTRUCTION

Environmental impacts of repository construction are due principally to resource commitments and to nonradiological effluents, i.e., pollutants released from vehicles and fugitive dust from surface handling operations of mined materials. Construction impacts to be discussed are those for construction of surface facilities and mining of the entire repository, and do not include any impacts from waste emplacement during the initial 5-year retrieval period. The repository is mined out completely by the end of the initial 5-year retrieval period. Construction impacts are the same for the three reprocessing fuel cycles although the number of repositories differs among the fuel cycles.

9.1.1 Resource Commitments

Granite and basalt repositories require approximately two times the resource commitments as salt and shale repositories. The same size repository is maintained in each rock medium (about 800 ha); however, different thermal criteria allow wastes to be stored closer together in granite and basalt repositories than in salt and shale repositories. Thus greater quantities of waste can be stored in granite and basalt repositories than in salt and shale repositories. Resource commitments necessary for construction of a reference repository in salt, granite, shale, and basalt formations are shown in Table 9.1-1.

TABLE 9.1-1. Resource Commitments Necessary for Construction of a Repository in Salt, Granite, Shale and Basalt

Resource	Salt	Granite	Shale	Basalt
Land use				
Surface facilities, ha	180	220	180	220
Access roads and railroads, ha	8	8	8	8
Mineral and surface rights, ha (fenced restricted area)	810	810	810	810
Additional land on which only subsurface activities will be restricted, ha	3,200	3,200	3,200	3,200
Water use, m^3	270,000	510,000	290,000	450,000
Materials				
Concrete, m^3	110,000	210,000	120,000	190,000
Steel, MT	18,000	33,000	19,000	30,000
Copper, MT	240	470	260	420
Zinc, MT	62	120	67	110
Aluminum, MT	46	90	50	77
Lumber, m^3	2,600	4,900	2,800	4,400
Energy resources				
Propane, m^3	2,400	4,500	2,600	4,000
Diesel fuel, m^3	24,000	45,000	26,000	40,000
Gasoline, m^3	18,000	33,000	19,000	30,000
Electricity				
Peak demand, kW	3,900	7,300	4,100	6,600
Total consumption, kWh	16,000,000	30,000,000	17,000,000	27,000,000
Manpower, man-yr	1.1×10^4	2.2×10^4	1.3×10^4	2.6×10^4

9.1.2 Nonradiological Effluents

Effluents from repository construction include dust and pollutants from machinery operation generated during surface facility construction and mining operations. Burning the quantities of fossil fuels listed in Table 9.1-1 results in air pollutant emissions, but concentrations in air at the fenceline are not expected to result in any air quality degradation outside of regulatory limits.[1] Estimates of pollutant totals released to the atmosphere from operating equipment during construction are given in Table 9.1-2. These quantities are developed from the total quantities of fuel burned and emission factors for a given effluent.[2]

TABLE 9.1-2. Total Quantities of Effluents Released to the Atmosphere During Construction of a Reference Geologic Repository, MT

Pollutant	Repository Medium: Salt	Granite	Shale	Basalt
Co	8,800	16,000	9,300	15,000
Hydrocarbons	400	740	420	660
NO_x	1,700	3,100	1,800	2,800
SO_x	100	190	110	170
Particulates	100	190	110	170

As in the case of the once-through fuel cycle repositories, the primary concern during construction of repositories for reprocessing fuel cycles is the quantity of mined material brought to the surface during mining. Dust from mining and transport within the mine is removed by filters in the mine ventilation system. However, dust generated from surface operations and from transport to storage is expected to result in the greatest dust generation.

Potential dust emissions are determined using emission factors estimated by Cowherd, et al.[3] These factors were measured for rock aggregate storage piles (not salt) under dry and windy conditions when the dust-generating potential was near maximum. Based on the maximum amount of material mined per day, Table 9.1-3 presents dust emissions for the various media for both the reference environment (moist regions) and arid regions.

TABLE 9.1-3. Maximum Dust Emissions From Surface Handling of Mined Material, MT/d

Climate	Repository Medium: Salt	Granite	Shale	Basalt
Reference	3.6	5.6	3.1	6.1
Arid	49	79	44	86

The maximum and average concentrations of dust at the repository fenceline (1.6 km from repository center) were calculated using the average annual dispersion factors ($\overline{X}/Q'$) presented for the reference environment. Table 9.1-4 presents these concentrations for the four geologic media.

TABLE 9.1-4. Dust Concentrations at Repository Fenceline, $\mu g/m^3$

Repository Medium	Concentration Maximum	Concentration Average
Salt		
Reference	130	71
Arid	1600	930
Granite		
Reference	200	120
Arid	2400	1400
Shale		
Reference	110	66
Arid	1400	790
Basalt		
Reference	210	130
Arid	2600	1600

The primary federal air quality standard for suspended particulate matter computed as an annual geometric mean is 75 $\mu g/m^3$. Thus, for both the reference site and any proposed arid site, this limit is exceeded without application of appropriate control techniques during surface handling of mined material.

To give perspective to the salt concentrations (in Table 9.1-4) at the repository fenceline, it may be noted that the particulate concentrations of sea salt near the shore on the eastern seaboard average about 140 $\mu g/m^3$ at 0.5 km inland and about one-tenth of that 1 km inland. During persistently high onshore winds, the particulate concentration may be on the order of 380 $\mu g/m^3$ at 0.5 km and 60 $\mu g/m^3$ at 1 km.[4]

Dust concentration estimates in Table 9.1-4 are primarily due to surface transfer operations and do not include dust emissions from crushing operations or transport. Dust emissions from accumulated surface storage of mined salt material are expected to be negligible under normal conditions because salt storage stockpiles crust quickly due to the ability of rock salt to absorb water vapor. Dust emissions from other media stored on the surface are not expected to be significant.

Table 9.1-5 presents dust depositions from surface handling of mined material. Maximum deposition of dust would occur at a distance of 0.4 km from surface handling operations. At the repository fenceline (1.6 km from the handling operations) depositions are approximately a factor of 10 less. These depositions are based on the "worst case," which would consider the maximum salt removal rate for a year. Impacts of these depositions are discussed in the ecological section.

TABLE 9.1-5. Dust Depositions from Surface Handling of Mined Materials, g/m^2/yr

Repository Medium	Dust Deposition: At 0.4 km from Handling Operation	Dust Deposition: At 1.6 km from Handling Operation
Salt		
Reference	90	11
Arid	1100	110
Granite		
Reference	140	17
Arid	1700	170
Shale		
Reference	79	9.7
Arid	970	97
Basalt		
Reference	160	19
Arid	1900	190

The main concern related to surface stockpiles will be to protect the ground and surface waters from being contaminated with stockpile runoff. The salt stockpiles will be of major concern. After grading the stockpile areas and before stockpiling material, an impermeable lining of hypalon covered by 2 ft of montmorillionite-type clay will be placed over the entire stockpile area. The hypalon and clay will function as a groundwater protection barrier. A trench with the same type of protection will be constructed all around the stockpile to collect the runoff water and transport it for the required treatment. If the mine is located in an area with a climate similar to New Mexico's climate, an evaporation pond may provide the required treatment. If an evaporation pond is not practical, the runoff water will be drained into a sump and pumped to a water treatment plant where dissolved salt will be removed.

Salt stockpiles crust quickly and industry does not spread asphalt or chemicals on top of stockpiles to prevent loss of salt through erosion. However, covering the piles with asphalt has been suggested and may be an appropriate means of assuring dust control.

Shale conceivably could contain amounts of soluble minerals that would be detrimental to the environment. Precipitation could leach these minerals and pollute surface and groundwaters. Moreover, in a cold climate freezing of the wet rock will result in fragmentation and liberation of clay particles responsible for mechanical pollution of the streams.

The shale stockpile area could be covered with a blanket of montmorillonite clay and sloped toward a collecting ditch. The surface water would then drain into a settling pond to collect silt and sands. From the pond it would be pumped to a water treatment plant where minerals in solution would be removed before release. Granite and basalt generally do not contain noxious soluble substances. Therefore, the stockpile area would not need special treatment and surface water would not have to be treated.

Water used during construction of the repository will be 2.7×10^5 to 5.1×10^5 m^3 over the 7-yr construction (mining) period. This water will be supplied from the R river; water use will represent a small fraction (<0.001) of the average river flow and no significant impact will result from its withdrawal.

Sanitary waste will be collected in a sewer system that is connected to a local sewer trunk, if available, or will be given secondary treatment at the repository and disposed of in accordance with local and federal regulations. Storm drains will be separate from the sanitary sewer system and will lead to a storm drainage pond in the general yard area.

Surface water runoff from excavation sites, drilling, and parking and laydown areas would be controlled to prevent it from reaching surface waters. One method of control is to direct runoff into a storm drainage pond.

9.1.3 Radiological Effects

Routine radiological releases from the geologic repository during construction will consist of naturally occurring radon and its daughter products released in the process of mining the repository. Radionuclides released annually to the biosphere for the various geologic media are listed in Table 9.1-6.

TABLE 9.1-6. Annual Radionuclide Releases to Air for Construction of Geologic Repository for Fuel Reprocessing Waste, Ci/yr

	Geologic Medium			
Nuclide	Salt	Granite	Shale	Basalt
^{220}Rn	1.1×10^{-3}	1.4×10^{1}	5.1	2.0
^{222}Rn	1.6×10^{-3}	1.3×10^{1}	6.0	1.7
^{210}Pb	1.3×10^{-7}	1.1×10^{-3}	2.5×10^{-4}	1.4×10^{-4}
^{212}Pb	1.7×10^{-6}	2.1×10^{-2}	7.7×10^{-3}	3.0×10^{-3}
^{214}Pb	1.6×10^{-3}	1.3×10^{1}	6.0	1.7
^{210}Bi	1.6×10^{-3}	1.3×10^{1}	6.0	1.7

Radiation doses in the vicinity of the repository during mining operations were calculated based on the releases of radioactive material as listed in Table 9.1-6. Dispersion will occur from a mine stack 110 m high with a flow rate of 240 m^3/sec and a release velocity of 10 m/sec. These doses were based on releases from mining operations and include doses from naturally occurring radon and its decay products. Exposure pathways, demography, and other parameters described for the reference environment are presented in Appendix A. Mathematical models relating dose to man from radionuclide releases are given in Appendix B. For planned operation of the repository, the only exposure pathway to man and to the environment is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 9.1-7. The annual total body dose from mine operations would be 1.4×10^{-5} rem for a repository in basalt compared with 0.1 rem from undisturbed naturally occurring radioactive sources. The calculated doses for the two recycle options (uranium and plutonium recycle and uranium-only recycle) are the same.

The combined dose from mine effluents to the population living within an 80-km radius of the repository was calculated using projected population data for the year 2000 (2×10^{6} persons) for the reference environment. Table 9.1-8 summarizes the annual doses received by this population. The largest annual total body population dose from mining effluents would be 2.6 man-rem for a repository in granite as given in Table 9.1-8, which may be compared with about 200,000 man-rem the population would otherwise receive from naturally occurring sources. Annual occupational doses are given in Table 9.1-9.

The 70-year doses to the maximum individual and to the population within 80 km of the repository are given in Tables 9.1-10 and 9.1-11, respectively. A summary of the 70-year total-body doses to the work force and population is given in Table 9.1-12. The largest 70-year population dose received from mine effluents is 68 man-rem for a repository in granite, which may be compared with about 1.4×10^{7} man-rem the population would otherwise receive from naturally occurring sources.

TABLE 9.1-7. Annual Doses to the Maximum Individual[a] From Radon and Decay Products During Mining Operations at the Geologic Repository for LWR Reprocessing Wastes, rem/yr

Pathway	Total Body	Thyroid	Lung	Bone
		Salt		
Air submersion	2.6×10^{-11}	2.6×10^{-11}	2.6×10^{-11}	2.6×10^{-11}
Inhalation	1.3×10^{-9}		4.9×10^{-10}	2.1×10^{-8}
Total	1.3×10^{-9}	2.6×10^{-11}	5.2×10^{-10}	2.1×10^{-8}
		Granite		
Air submersion	2.1×10^{-7}	2.1×10^{-7}	2.1×10^{-7}	2.1×10^{-7}
Inhalation	1.0×10^{-5}		3.9×10^{-4}	1.7×10^{-4}
Total	1.0×10^{-5}	2.1×10^{-7}	3.9×10^{-4}	1.7×10^{-4}
		Basalt		
Air submersion	2.8×10^{-8}	2.8×10^{-8}	2.8×10^{-8}	2.8×10^{-8}
Inhalation	1.4×10^{-5}		5.2×10^{-4}	2.3×10^{-5}
Total	1.4×10^{-5}	2.8×10^{-8}	5.2×10^{-4}	2.3×10^{-5}
		Shale		
Air submersion	9.8×10^{-8}	9.8×10^{-8}	9.8×10^{-8}	9.8×10^{-8}
Inhalation	4.8×10^{-6}		1.9×10^{-6}	8.0×10^{-5}
Total	4.9×10^{-6}	9.8×10^{-8}	2.0×10^{-6}	8.0×10^{-5}

a. The maximum individual is defined as a permanent resident at a location 4000 m southeast of the stack with the highest annual average dispersion factor (χ/Q') of 1.3×10^{-8} sec/m^3.

TABLE 9.1-8. Annual Doses to the Population (within 80 km) from Radon and Decay Products During Mining Operations at the Geologic Repository for LWR Reprocessing Wastes, man-rem/yr

Pathway	Total Body	Thyroid	Lung	Bone
		Salt		
Air submersion	6.2×10^{-6}	6.2×10^{-6}	6.2×10^{-6}	6.2×10^{-6}
Inhalation	3.0×10^{-4}		1.2×10^{-4}	5.1×10^{-3}
Total	3.1×10^{-4}	6.2×10^{-6}	1.3×10^{-4}	5.1×10^{-3}
		Granite		
Air submersion	5.1×10^{-2}	5.1×10^{-2}	5.1×10^{-2}	5.1×10^{-2}
Inhalation	2.5		1.0	4.1×10^{1}
Total	2.6	5.1×10^{-2}	1.0	4.1×10^{1}
		Basalt		
Air submersion	6.8×10^{-3}	6.8×10^{-3}	6.8×10^{-3}	6.8×10^{-3}
Inhalation	3.3×10^{-1}		1.3×10^{-1}	5.5
Total	3.4×10^{-1}	6.8×10^{-3}	1.4×10^{-1}	5.5
		Shale		
Air submersion	2.4×10^{-2}	2.4×10^{-2}	2.4×10^{-2}	2.4×10^{-2}
Inhalation	1.2		4.5×10^{-1}	1.9×10^{1}
Total	1.2	2.4×10^{-2}	4.7×10^{-1}	1.9×10^{1}

TABLE 9.1-9. Summary of Annual Total-Body Doses Received from Mining Operations at the Geologic Repository for LWR Reprocessing Wastes and from Naturally Occurring Sources, man-rem/yr

Fuel Cycle	Repository Medium			
	Salt	Granite	Shale	Basalt
Work force				
U and Pu recycle	7.8×10^{-2}	4.2×10^{2}	1.9×10^{2}	4.9×10^{2}
U-only recycle, Pu in HLW	2.1×10^{-2}	4.1×10^{2}	1.9×10^{2}	4.8×10^{2}
U-only recycle, PuO_2 stored	6.5×10^{-2}	4.1×10^{2}	1.9×10^{2}	4.8×10^{2}
Population (within 80 km)				
All fuel cycles	3.1×10^{-4}	2.6	1.2	3.4×10^{-1}
Naturally occurring sources (other than from radon released during mining)	2×10^{5}	2×10^{5}	2×10^{5}	2×10^{5}

TABLE 9.1-10. 70-Year Doses to the Maximum Individual[a] From Radon and Decay Products During Mining Operations at the Geologic Repository for LWR Reprocessing Waste, rem

Pathway	Total Body	Thyroid	Lung	Bone
		Salt		
Air submersion	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}
Inhalation	3.4×10^{-8}		3.8×10^{-9}	1.0×10^{-6}
Total	3.4×10^{-8}	1.8×10^{-10}	4.0×10^{-9}	1.0×10^{-6}
		Granite		
Air submersion	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}
Inhalation	2.8×10^{-4}		3.1×10^{-5}	8.5×10^{-3}
Total	2.8×10^{-4}	1.4×10^{-6}	3.2×10^{-5}	8.5×10^{-3}
		Basalt		
Air submersion	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}
Inhalation	3.7×10^{-5}		4.1×10^{-6}	1.1×10^{-3}
Total	3.7×10^{-5}	1.9×10^{-7}	4.3×10^{-6}	1.1×10^{-3}
		Shale		
Air submersion	6.7×10^{-7}	6.7×10^{-7}	6.7×10^{-7}	6.7×10^{-7}
Inhalation	1.3×10^{-4}		1.5×10^{-5}	4.0×10^{-3}
Total	1.3×10^{-4}	6.7×10^{-7}	1.6×10^{-6}	4.0×10^{-3}

a. The maximum individual is defined as a permanent resident at a location 4000 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.3×10^{-8} sec/m^3.

TABLE 9.1-11. 70-Year Doses to Population (Within 80 km) from Radon and Decay Products During Mining Operations at the Geologic Repository for LWR Reprocessing Wastes, man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		Salt		
Air submersion	4.3×10^{-5}	4.3×10^{-5}	4.3×10^{-5}	4.3×10^{-5}
Inhalation	8.5×10^{-3}		9.2×10^{-4}	2.6×10^{-1}
Total	8.5×10^{-3}	4.3×10^{-5}	9.6×10^{-4}	2.6×10^{-1}
		Granite		
Air submersion	3.2×10^{-1}	3.2×10^{-1}	3.2×10^{-1}	3.2×10^{-1}
Inhalation	6.8×10^{1}		7.4	2.1×10^{3}
Total	6.8×10^{1}	3.2×10^{-1}	7.7	2.1×10^{3}
		Basalt		
Air submersion	4.8×10^{-2}	4.8×10^{-2}	4.8×10^{-2}	4.8×10^{-2}
Inhalation	9.2		1.0	2.8×10^{2}
Total	9.2	4.8×10^{-2}	1.0	2.8×10^{2}
		Shale		
Air submersion	1.7×10^{-1}	1.7×10^{-1}	1.7×10^{-1}	1.7×10^{-1}
Inhalation	3.2×10^{1}		3.5	9.8×10^{2}
Total	3.2×10^{1}	1.7×10^{-1}	3.7	9.8×10^{2}

TABLE 9.1-12. Summary of 70-Year Total-Body Doses from Mining Operations at the Geologic Repository for LWR Reprocessing Wastes and from Naturally Occurring Sources, man-rem

Fuel Cycle	Repository Medium Salt	Granite	Shale	Basalt
Work force				
U and Pu recycle	3.5×10^{-1}	2.9×10^{3}	1.3×10^{3}	3.4×10^{3}
U-only recycle, Pu in HLW	1.5×10^{-1}	2.9×10^{3}	1.3×10^{3}	3.4×10^{3}
U-only recycle, PuO_2 stored	4.5×10^{-1}	2.9×10^{3}	1.3×10^{3}	3.3×10^{3}
Population (within 80 km)				
All fuel cycles	8.5×10^{-3}	6.8×10^{1}	3.2×10^{1}	9.2
Naturally occurring sources (other than from radon released during mining)	1.4×10^{7}	1.4×10^{7}	1.4×10^{7}	1.4×10^{7}

In this report, 100 to 800 health effects are postulated to result in the exposed population per million man-rem. Based on the calculated doses to the regional population, no health effects are expected to result from planned operation of the geologic repository for LWR reprocessing wastes.

9.1.4 Ecological Effects

Ecological effects of repository construction for the reprocessing fuel cycles are expected to be similar to those of the once-through cycle (see Section 4.4). Impacts from salt repository construction for these fuel cycles are greater than for the once-through cycle option because about 20% more salt is mined. Impacts of granite, shale, and basalt repository construction are less than impacts of the once-through cycle option because about 32%, 15%, and 34% less materials, respectively, are mined. Again the major ecological impact is from dust depositions that occur from surface handling operations of mined material. Of greatest concern is the potential for salt depositions at the salt repository fenceline of 11 and 110 g/m^2-yr for the reference and arid environments, respectively.

9.1.5 Socioeconomic Impacts of Construction

Socioeconomic impacts of repository construction are discussed together with impacts of operation (Section 9.2).

9.1.6 Impacts of Nonradiological Accidents

Table 9.1-13 summarizes the predicted injuries and fatalities associated with surface facility construction and underground mining operations for the various geologic media. These predictions are based on an injury rate of 13.6 disabling injuries per million hours of construction[4] on the surface facilities and an injury rate of 25 disabling injuries per million man-hours of underground mining (other than coal). A fatality rate of 0.17 fatalities per million man-hours of construction[5] on the surface facilities and 0.53 fatalities per million man-hours of underground mining (other than coal) were also used.

TABLE 9.1-13. Nonradiological Disabling Injuries and Fatalities Associated with Repository Construction

	Geologic Medium			
	Salt	Granite	Shale	Basalt
Surface facility construction				
Disabling injuries	84	84	84	84
Fatalities	1	1	1	1
Underground mining operations				
Disabling injuries	420	1000	510	1200
Fatalities	9	21	11	25
Total				
Disabling injuries	500	1100	590	1300
Fatalities	10	22	12	26

One additional nonradiological accident was analyzed. In this accident, a tornado is postulated to strike a surface storage pile comprised of mined material from the geologic repository. Impacts from this accident would be identical to those from the once-through cycle option, discussed in Section 4.4.1.1.

9.1.7 Radiological Accidents

No radiological accidents are postulated because impacts from wastes received during the initial 5-yr retrieval period are considered under operational impacts (Section 9.2).

REFERENCES FOR SECTION 9.1

1. "National Primary and Secondary Ambient Air Quality Standards," Code of Federal Regulations, Title 40, Part 50.

2. Air Quality Impacts Due to Construction at LWR Waste Management Facilities, URS Company, URS 7043-01- 01, June 1977.

3. C. Cowherd, Jr., et al., Development of Emission Factors for Fugitive Dust Sources, P B-238262 NTIS (EPA-450/3-74-037), Midwest Research Institute, 1974.

4. Cooling Tower Environment, ERDA Symposia Series, CONF 740302, pp. 353-369, 1974.

5. Accident Facts, National Safety Council, Chicago, IL, p. 11, 1974.

9.2 ENVIRONMENTAL EFFECTS RELATED TO FACILITY OPERATION

9.2 ENVIRONMENTAL EFFECTS RELATED TO FACILITY OPERATION

The operational phase of the repositories for reprocessing fuel cycles includes the receiving and handling of wastes, placement of waste canisters into assigned subterranean storage areas, and the subsequent backfilling of these areas when full. The maximum storage capacity of a geologic repository in the media considered will be reached after approximately the following time periods:

Repository Medium	Operational Phase, yr
Salt	19*
Granite	20
Shale	13
Basalt	18

9.2.1 Resource Commitments

The repository operates on a 5-day week, three shifts per day. An operating efficiency of 67% is assumed. Resource commitments for operation of the geologic repository are summarized in Table 9.2-1.

TABLE 9.2-1. Resource Commitments for the Operational Phase of the Geologic Repository(a)

Material	Geologic Medium			
	Salt	Granite	Shale	Basalt
HLW canister overpacks, MT steel(b,c)	6.4	8.2	4.8	9.0
FRW/ILW canister overpacks, MT steel	1.5×10^1	1.6×10^1	1.0×10^1	1.4×10^1
ILW drum packs, MT steel	5.3×10^4	5.8×10^4	3.0×10^4	4.9×10^4
HLW retrievability sleeves, MT steel(c,d)	7.3×10^2	9.6×10^2	1.3×10^3	1.3×10^3
FRW/ILW retrievability sleeves, MT steel(d)	2.9×10^4	1.9×10^5(e)	2.9×10^4	1.6×10^5(e)
HLW concrete plug, MT concrete(d)	8.0×10^2	1.0×10^3	1.4×10^3	1.4×10^3
FRW/ILW concrete plug, MT concrete(d)	7.2×10^4	7.2×10^4	7.2×10^4	7.2×10^4
Energy				
Electricity, kwh	2.1×10^9	2.6×10^9	1.4×10^9	2.3×10^9
Coal, MT	1.4×10^6	1.4×10^6	9.4×10^5	1.3×10^6
Diesel fuel, m^3	2.5×10^5	2.6×10^5	1.7×10^5	2.3×10^5
Steam, MT	1.5×10^7	1.6×10^7	1.0×10^7	1.4×10^7
Manpower, man-yr	1.9×10^4	2.4×10^4	1.3×10^4	2.1×10^4

a. Estimates presented in this table are for the U and Pu recycle option; other options vary <20%.
b. Overpack requirements are based on 0.1% of canisters received leaking or damaged.
c. HLW canister and sleeve diameters change with time as necessary to maintain canister heat output within limits.
d. Sleeves and plugs needed for first five years only.
e. Sleeves are required for the entire operational period.

* For the full recycle option only; operational phase for the U recycle only, Pu in waste option is 15 yr; and for the U recycle only, Pu in PuO_2 storage option, the operational phase is 21 yr.

9.2.2 Nonradiological Effluents

The major nonradiological effluent from facility operation would be fugitive dust emissions from surface handling operations of mined materials, as was discussed under construction impacts. Other nonradiological pollutants released to the biosphere during the repository's operational life are given in Table 9.2-2 for the various geologic media. These pollutants include combustion products from burning diesel fuel[1] during underground mining operations and from surface burning of coal.[2]

TABLE 9.2-2. Total Quantities of Effluents Released to the Atmosphere During Operation of the Geologic Repository

Effluent	Geologic Medium			
	Salt	Granite	Shale	Basalt
Particulates, MT	510	540	350	480
SO_x, MT	12,000	12,000	7,800	11,000
CO, MT	2,900	3,000	2,000	2,700
Hydrocarbons, MT	1,000	1,100	710	980
NO_x, MT	17,000	19,000	12,000	17,000
Heat, MJ	7.6×10^8	8.3×10^8	4.3×10^8	7.0×10^8

For comparison, the emission from space heaters in a town of 30,000 was estimated for a 20-yr period. Assuming that furnace oil was the fuel and that it had a sulfur content of 1%, the following total emissions were calculated:

Particulates, MT	460
SO_2, MT	6,000
CO, MT	220
Hydrocarbons, MT	120
NO_x, MT	540

The estimated releases of pollutants from a geologic repository would not in any case result in Federal Air Quality Standards being exceeded at the repository boundary.

Heat released from buried nuclear waste will increase the temperature of the geologic formation in which it is buried and may alter the physical and chemical properties of the formation. The heat will eventually be transferred to the atmosphere and, if the temperatures and temperature gradients have not exceeded values that would cause damage to the formation or adversely affect the containment integrity or the environment, the formation will return essentially to its initial state.

Thermal effects that influence the allowable temperature rises and heat release rates include:

- thermal stability of the waste
- thermal stability of the formation

- movement of water in formation pores and openings
- structural integrity of the formation over its entire area
- temperature rise in any nearby freshwater aquifers
- heating of the earth's surface
- temperature increased beyond the boundaries of the disposal area.

Thermal criteria for limiting adverse thermal effects are a function of each formation and setting and are difficult to establish in a generic setting. Criteria, in terms of maximum temperature, were developed for bedded salt and applied to a proposed repository in Lyons, Kansas.(3) The criteria were established using waste canister centerline temperatures ranging from 650° to 1100°C. In general, 1% or less of the salt immediately surrounding the waste canister is allowed to rise 210°C in temperature, and 25% or less of the salt is allowed to rise 160°C. These temperature rises correspond to limiting temperatures of 200°C and 250°C, respectively, for the proposed depths at which the ambient temperature is about 22°C.

From an environmental standpoint, maximum temperature increases from this analysis were 0.6°C at the surface, 28°C in assumed (hypothetical) stagnant freshwater aquifers above the repository, and 0.6°C in geologic formations at the outer edge of the repository buffer zone. Because of the low heat flux in the vicinity of the aquifers, only a small flow rate would keep the temperature rise well below that for a stagnant aquifer.

The thermal conductivity of the geologic medium is the most important single variable that controls the temperature distribution in the disposal medium. In general, the thermal conductivity of a salt formation is about twice that of other geologic materials and about twice the temperature rise would be expected in other materials for a given power output of the waste.

The water content of the rocks has a strong effect on the thermal conductivity, and under certain conditions thermal effects may produce hydrofracturing or water migration. The behavior of pore water, when a geologic formation is heated, is not completely understood. Water occurring as brine occlusions in salt is known to migrate upgradient toward the heat source. However, the small amount of brine (about 0.5%) present in occlusions is expected to have little effect on the thermal conductivity of the surrounding medium.

Effects at the ground surface from repository operations and final sealing for disposal are a combination of two effects: lowering of the surface caused by the plastic flow of salt into the mine area and a surface uplift from expansion caused by thermal effects. Results of preliminary calculations by the Office of Waste Isolation(4) using an arbitrary repository design indicate that a maximum surface subsidence of about 1.2 m would occur after extensive plastic flow in the mine pillars. The result would be a broad, flat, saucer-shaped depression that would be created over the repository site. From the same calculations, excluding all other effects, it was estimated that thermal expansion of the entire rock column above and to some depth below the mine would cause the ground surface to first rise to a maximum of about 1.5 m after 200 years and then, as the heat dissipated, slowly return to its original position over several thousand years.

The actual ground surface behavior would result from a combination of effects of subsidence and gradual uplifting. Subsidence would be partially cancelled by upward movement from thermal expansion for 30 to 40 years, after which expansion effects would dominate, thus producing a net uplift of the surface, which would reach a maximum of about 0.3 m about 200 years after repository operations begin. The surface would gradually subside, passing through its original position and, thousands of years later, reach a final position of about 1.2 m below the original elevation.

The broad, slight subsidence indicated in this analysis is not believed to be a significant change in the landscape. The surface change is minor in scale and would occur so slowly that adjustments would probably take place during the process. For example, argillaceous materials such as shales and clays are known to exhibit slow plastic deformation over long periods of time instead of fracturing. There are no indications that the overlying rock material would not be able to absorb the strains and displacements over the thousands of years during which they would occur.

For other settings and geologic media, rock deformation and its effects on the integrity of containment will depend on the rock material present at a given site and will need to be evaluated for that site.

The rock immediately surrounding spent fuel will be exposed to gamma rays and a few neutrons from the waste. The gamma ray energy deposited in the rock material surrounding the spent fuel will depend on the type of fission product activity, the age of the spent fuel in the canister, canister material and thickness, and the proximity of the rock to the canister.[5] The energy deposition and deposition rate will decrease exponentially with increasing distance from the surface of the waste canister. For example, with a canister 0.3 m in diameter, the energy deposition at 0.15 m from the canister surface is one-tenth that at the surface.[6] The energy deposition in the rock from neutrons will be negligible.[6]

Gamma radiation produces lattice damage and thus causes the generation of stored energy in salt crystals. Under certain conditions the accumulation of stored energy can be appreciable. Experimental studies have been conducted to determine the amounts of gamma ray energy stored in salt under exposure conditions similar to those of a salt repository and also the release characteristics of this energy.[5] Some annealing or release of the stored energy will occur in the repository, depending on temperature and other factors. At 150°C and above, thermally activated annealing will be the dominant process and will limit the accumulation of stored energy. Rates of annealing at repository temperatures <150°C are not well known.

In general, no conditions are known that would promote a sudden release of stored energy in repository salt other than rapid heating of the salt by several hundred degrees by a source other than the contained stored energy. No such source of external heat is apparent.[5] It was estimated that no serious adverse effects on waste containment and safe repository operation would result if, because of unforeseen circumstances, a release of the entire amount of stored energy in the waste within a canister and within the surrounding salt were to occur.[6]

Irradiated salt is known to yield hydrogen upon aqueous dissolution,(7) and there is evidence that irradiated salt may dissolve more rapidly than salt that has not been irradiated. However, unless the repository is breached and fresh water contacts the salt surrounding the canisters, no generation of hydrogen is expected.

9.2.3 Radiological Releases

Routine radiological releases from a geologic repository during normal operation will consist of naturally occurring radon and its decay products. These releases will occur from backfilling operations and are assumed to be negligible compared to radon releases during repository construction. Resultant doses to the regional population will also be considered negligible.

Doses to the work force during repository operation will include contributions from receiving, handling, and placement of spent fuel canisters into proper subterranean storage areas. These doses are presented below for the various geologic media:

Geologic Medium	70-Year Total Body Dose, man-rem
Salt	1.4×10^5
Granite	1.6×10^5
Shale	8.0×10^4
Basalt	1.3×10^5

9.2.4 Ecological Impacts

The major ecological impact of operation would be from the handling of mined materials at the surface during repository mining and backfilling. Impacts would be due to the airborne transfer of mined particulates to the environment near the site. These impacts would be greatest for the repository in salt. Mitigating procedures may be necessary to control this potential threat to the environment.

9.2.5 Socioeconomic Impacts

Socioeconomic impacts associated with the construction and operation of repositories are dependent largely on the number of persons who move into the county in which the facility will be located. Because of this, the size of the local project-generated population influx was forecasted, and estimates of their needs for locally provided social services were determined. Specific economic and fiscal impacts attributable to the development of the repository will not be treated here because they are too dependent on local site characteristics to allow for generalization.

Socioeconomic impacts also depend on site characteristics (see Appendix C) and the assumptions used in the forecasting model. Site characteristics that are especially important in influencing the size of the impacts forecasted include the availability of a local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (population size, degree of urbanization, etc.) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites, identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible, and they differ substantially in demogrpahic characteristics, thus providing a reasonable range of socioeconomic impacts.

The socioeconomic model employed in this analysis forecasts a regional population in 5-yr intervals in the absence of any project activities. This population forecast serves both as a comparative baseline and as a source for a portion of the postulated future project employment. The model takes account of both primary and secondary employment effects (such as additional retail store clerks) and incorporates as separate components spouses of members of the labor force and other dependents. Projected residences of regional migrants associated with the project are distributed to counties throughout the commuting region. The model accounts for separation and retirement from project employment and replacement by new labor force members. It also accounts for the tendency of workers and their dependents to leave the region upon job separation.

In the following analysis, impacts are presented in terms of an expected level of impact as well as a maximum level of impact. The expected impact condition is based on the most likely value of model assumptions, whereas the maximum impact condition places an extreme but credible value on the model assumptions.

Table 9.2-3 presents the manpower requirements for construction and operation of a single waste repository involving reprocessing of wastes.

TABLE 9.2-3. Manpower Requirements for Construction and Operation of a Single Waste Repository, U and Pu Recycle, by Disposal Medium and Impact Condition, mean man-yr/yr

Repository Medium	Construction	Operation
Salt	1,570	1,000
Granite	3,140	1,200
Shale	1,860	1,000
Basalt	3,710	1,170

Tables 9.2-4 through 9.2-7 present estimates of the cumulative project-related in-migrants for the three reference repository sites in each of the four disposal media (salt, granite, shale, and basalt). The forecasted values include primary and secondary workers and associated household dependents, all of whom are in-migrants. Some of the persons who separate from the facility will stay in the site county and some will leave. Those who will stay are included in the forecasted values. Thus, not all forecasted populations are actually working on or directly associated with the project at each time period. Nevertheless, the presence of each of these persons would be caused by the existence of the project; they would probably not be present if the project did not occur. The percentages associated with each population in these tables reflect the size of the in-migrant group relative to the baseline population in the respective sites. Since these baseline populations vary by site, the relative impact of a similar in-migrant group can vary greatly.

TABLE 9.2-4. Forecasts of Population Influx for a Geologic Repository in Salt, Reprocessing (U and Pu Recycle), Number of Persons and % of Base Population

Site	1980		1985		2000		2005	
			Expected Impact Condition					
Southeast	290	(1.4%)	680	(2.9%)	800	(2.9%)	820	(2.9%)
Midwest	110	(0.2%)	1,600	(2.1%)	1,800	(2.0%)	1,900	(2.0%)
Southwest	4,900	(10.0%)	5,800	(11.1%)	6,900	(12.0%)	7,000	(11.9%)
			Maximum Impact Condition					
Southeast	3,800	(15.0%)	6,800	(22.9%)	8,200	(23.8%)	8,400	(23.6%)
Midwest	1,200	(2.0%)	3,700	(4.8%)	4,300	(4.6%)	4,500	(4.6%)
Southwest	7,300	(14.2%)	12,000	(20.7%)	14,000	(22.4%)	15,000	(22.2%)

TABLE 9.2-5. Forecasts of Population Influx for a Geologic Repository in Granite, Reprocessing (U and Pu Recycle), Number of Persons and % of Base Population

Site	1980		1985		2000		2005	
			Expected Impact Condition					
Southeast	720	(5.3%)	940	(3.9%)	1,100	(4.0%)	1,100	(4.0%)
Midwest	520	(0.9%)	2,200	(2.9%)	2,600	(2.8%)	2,700	(2.8%)
Southwest	10,000	(18.3%)	9,400	(16.9%)	11,000	(18.3%)	12,000	(18.2%)
			Maximum Impact Condition					
Southeast	8,600	(28.8%)	11,000	(31.7%)	13,000	(32.9%)	13,000	(32.6%)
Midwest	6,300	(9.4%)	10,000	(12.5%)	12,000	(12.2%)	13,000	(12.1%)
Southwest	15,000	(25.3%)	16,000	(26.2%)	20,000	(28.5%)	20,000	(27.9%)

TABLE 9.2-6. Forecasts of Population Influx for a Geologic Repository in Shale, Reprocessing (U and Pu Recycle), Number of Persons and % of Base Population

Site	1980		1985		2000		2005	
			Expected Impact Condition					
Southeast	370	(1.7%)	710	(3.0%)	830	(3.1%)	850	(3.1%)
Midwest	150	(0.2%)	1.600	(2.2%)	1.900	(2.1%)	1.900	(2.0%)
Southwest	5,900	(11.8%)	6,300	(12.0%)	7,500	(13.0%)	7,700	(12.9%)
			Maximum Impact Condition					
Southeast	4,600	(18.0%)	7,300	(24.1%)	8,800	(25.0%)	9,000	(24.8%)
Midwest	2,100	(3.3%)	4,700	(6.0%)	5,500	(5.8%)	5,700	(5.8%)
Southwest	8,700	(16.5%)	12,000	(21.3%)	15,000	(22.9%)	15,000	(22.8%)

TABLE 9.2-7. Forecasts of Population Influx for a Geologic Repository in Basalt, Reprocessing (U and Pu Recycle), Number of Persons and % of Base Population

Site	1980		1985		2000		2005	
			Expected Impact Condition					
Southeast	870	(3.9%)	980	(4.1%)	1,100	(4.2%)	1,200	(4.2%)
Midwest	691	(1.1%)	2,300	(3.0%)	2,700	(2.9%)	2,800	(2.9%)
Southwest	12,000	(21.6%)	10,000	(18.3%)	12,000	(19.8%)	13,000	(19.7%)
			Maximum Impact Condition					
Southeast	10,000	(32.7%)	12,000	(33.3%)	14,000	(34.5%)	14,000	(34.3%)
Midwest	8,000	(11.9%)	12,000	(14.7%)	15,000	(14.3%)	15,000	(14.3%)
Southwest	18,000	(28.6%)	17,000	(26.7%)	20,000	(28.7%)	21,000	(28.5%)

Manpower requirements for construction of disposal facilities are lowest for a repository in salt and highest for a repository in basalt. Impacts associated with these facilities will be discussed below; effects associated with the remaining two facilities fall between these two extreme cases.

For a repository in salt under expected impact conditions, the total number of forecasted in-migrants in the Southeast and Midwest sites is under 3% of the site county populations in the construction (1980-1984) and operation (1985-2005) phases. In-migration at this level is not likely to produce significant impacts. The effect of a repository in salt at the Southwest site is substantially different. The number of in-migrants during construction is over three times the level of primary employment demand (4,926 versus 1,570). As a percent of projected baseline population size, the potential for significant impacts is much greater in the Southwest. Project-related in-migration that exceeds 10% of the corresponding baseline population is considered to produce significant impacts.

For a repository in basalt, expected impacts at the Southeast and Midwest site are also judged to be insignificant. As a percent of the baseline population, the forecasted numbers of in-migrants barely exceed 4% in the operation phase at the Southeast site (Table 9.2-7). Again, the Southwest site is subjected to relatively large impacts, primarily because there is a scarcity of skilled available local labor.

The maximum impact condition (see Tables 9.2-4 and 9.2-7) produces substantially larger project-induced in-migrant flows for each site and disposal medium compared with the expected conditions. Very severe impacts are forecasted for the Southeast and Southwest sites, though the likelihood of these impacts occurring is not great for two reasons. First, the manpower estimates and model assumptions have been set to produce an upper bound on social impacts. Second, in-migration at these levels would produce unacceptable local imbalances in the service infrastructure, which would result in greater turnover on the project and increased out-migration from the site county. These kinds of effects are not modeled in the forecasting procedures used here. Although the numbers of in-migrants are smaller, the potential for impacts in the Southeast maximum impact condition is greater than the potential in the Southwest site (under expected

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conditions for each disposal medium). This is the case because the base population in the Southwest site is roughly twice that in the Southeast site; therefore, the Southwest site is capable of absorbing greater population influx, other things being equal. The absolute numbers of new in-migrants and the size of this in-migrant group relative to the size of the baseline county population are both important factors in assessing impacts. In addition, the population size of the region which contains the site is important because it determines the non-migrant supply of labor for the project. The Southeast regional population is almost four times that in the Southwest region, while the Southwest county population is more than double the county population in the Southeast county.

The translation of forecasted project-related in-migration into socioeconomic impacts is complex and imprecise. Estimates of the level of demand that will be placed on the community to provide social services to the new workers and their families were made by applying a set of factors (see Appendix C) to the project in-migration values. The product indicates how many units of each social service would be "expected" by the in-migrants. The severity of these impacts is primarily related to the capacity of the site county to meet these expectations.

The calculated levels of expected and maximum need for additional social services at the three reference sites are given in Tables 9.2-8 through 9.2-11, respectively. Identification of social services that are likely to be required establishes the potential for the socioeconomic impacts. The ability of communities to provide services identified here, with or without financial assistance, is highly site specific and is beyond the scope of this document. Some of the social services listed can be described as operational, such as physicians and teachers. These needs are easily met on a temporary, less costly basis than are those services that require major capital investment. The latter services include hospital beds, classroom space, and additional waste treatment capacity. Capital investment needs are forecasted to be large, especially in the Southwest site, and to the extent that they persist over time, they will represent a serious challenge to community planners and local government. The increase in the local crime rate is only one indicator of the social disruption and a sense of a decline in social well being experienced by community residents faced with large-scale development.

In general, the reference Southwest site is more likely to sustain significant socio-economic impacts than the other two sites because it has a smaller available unemployed construction labor force, lacks a nearby metropolitan center, and is subject to the generation of greater secondary employment growth. If a repository were to be built in an area where demographic conditions approximated that of the Southwest site, a detailed analysis of site-specific socioeconomic impacts would be necessary to prevent serious disruptions in provision for needed social services.

9.2.6. Nonradiological Accidents

The postulated tornado strike of the uncovered surface storage piles could occur during the operational phase of the repository prior to completion of mine backfilling. Impacts of this accident are presented under construction impacts (Section 9.1).

TABLE 9.2-8. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Salt: Reprocessing (U and Pu Recycle)

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	2	7	7	6	14
Nurses	2	9	18	24	22	37
Dentists	0	1	2	2	3	5
Hospital beds	3	11	23	31	26	48
Nursing care beds	2	11	15	15	25	30
Education						
Teachers (K-12)	10	22	87	105	51	100
Classroom space (9-12), m^2	1,400	3,200	11,000	13,000	7,000	23,000
Sanitation, m^3/day						
Water treatment	450	1,000	3,900	4,600	2,500	8,200
Liquid waste	300	700	2,600	3,100	1,600	5,500
Safety						
Firemen	1	1	5	6	3	10
Policemen	2	4	14	16	9	29
Recreation, ha						
Neighborhood parks	1	1	6	7	3	12
Government						
Administrative staff	1	2	6	7	4	13
Other social impacts						
Crimes (7 crime index)	37	79	401	380	190	850

TABLE 9.2-9. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Granite: Reprocessing (U and Pu Recycle)

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	3	11	11	17	19
Nurses	3	13	29	38	61	51
Dentists	0	2	4	4	7	6
Hospital beds	4	15	38	48	73	65
Nursing care beds	2	15	24	23	67	41
Education						
Teachers (K-12)	13	30	140	170	150	260
Classroom space (9-12), m^2	1,800	4,200	18,000	20,000	19,000	31,000
Sanitation, m^3/day						
Water treatment	630	1,500	6,400	7,300	7,000	11,000
Liquid waste	420	970	4,300	4,900	4,700	7,400
Safety						
Firemen	1	2	8	9	8	13
Policemen	2	5	23	26	25	39
Recreation, ha						
Neighborhood parks	1	2	9	11	10	16
Government						
Administrative staff	1	2	10	12	11	18
Other social impacts						
Crimes (7 crime index)	51	111	660	600	530	1,200

TABLE 9.2-10. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Shale: Reprocessing (U and Pu Recycle)

Selected Social Services	Year 2000 Expected Demand Southeast Site	Midwest Site	Southwest Site	Maximum Demand Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	3	7	8	7	14
Nurses	2	9	19	26	27	39
Dentists	0	1	2	2	3	5
Hospital beds	3	11	25	33	32	50
Nursing care beds	2	11	16	16	32	31
Education						
Teachers (K-12)	10	22	96	110	64	190
Classroom space (9-12), m^2	1,400	3,200	12,000	14,000	8,800	23,000
Sanitation, m^3/day						
Water treatment	470	1,100	4,200	5,000	3,100	8,500
Liquid waste	310	710	2,800	3,300	2,100	5,700
Safety						
Firemen	1	1	5	6	4	10
Policemen	2	4	15	18	11	30
Recreation, ha						
Neighborhood parks	1	2	6	7	5	13
Government						
Administrative staff	1	2	7	8	5	14
Other social impacts						
Crimes (7 crime index)	38	81	440	410	240	880

TABLE 9.2-11. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Basalt: Reprocessing (U and Pu Recycle)

Selected Social Services	Year 2000 Expected Demand Southeast Site	Midwest Site	Southwest Site	Maximum Demand Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	4	12	12	20	19
Nurses	3	13	32	41	74	52
Dentists	0	2	4	4	9	6
Hospital beds	4	16	41	52	88	67
Nursing care beds	2	15	26	25	80	42
Education						
Teachers (K-12)	13	31	160	180	190	260
Classroom space (9-12), m^2	1,830	4,300	20,000	21,000	22,000	31,000
Sanitation, m^3/day						
Water treatment	650	1,500	7,100	7,900	8,500	11,000
Liquid waste	430	1,000	4,700	5,200	5,700	7,700
Safety						
Firemen	1	2	8	9	10	14
Policemen	2	5	25	28	30	41
Recreation, ha						
Neighborhood parks	1	2	10	12	13	17
Government						
Administrative staff	1	2	11	13	14	18
Other social impacts						
Crimes (7 crime index)	53	120	730	640	640	1,200

REFERENCES FOR SECTION 9.2

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4. Office of Waste Isolation, Contribution to Draft Environmental Impact Statement on Commercial Waste Management: Radioactive Waste Isolation in Geologic Formations. Draft Y/OWI/INF-11, Oak Ridge, TN, May 1977.

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9.3 ENVIRONMENTAL EFFECTS RELATED TO POSTULATED ACCIDENTS

9.3 ENVIRONMENTAL EFFECTS RELATED TO POSTULATED ACCIDENTS

Several minor, moderate, and non-design basis accidents were postulated for the geologic repository for LWR reprocessing wastes. No severe accidents (as defined for this report) were identified for the repository since non-design basis accidents have greater consequences than severe accidents. The accidents analyzed were chosen on a basis of a greater probability of occurrence and greater radiological risks. Scenarios are provided in Section 7.3.1.9 of DOE/ET-0028[1] and the accidents are listed in Table 9.3-1.

TABLE 9.3-1. Postulated Accidents for the Geologic Repository for LWR Reprocessing Wastes

Accident Number	Accident
	Minor
7.1[a]	Low-level transuranic waste drum rupture due to handling error
7.2	Minor canister failure due to rough handling
7.3	Externally contaminated canister
7.4	Receipt of dropped shipping cask
	Moderate
7.5	Canister drop in surface facility
7.6[a]	Canister drop down mine shaft
7.7	Tornado strikes salt storage piles
7.8	LLW drum rupture due to mechanical damage and fire
7.9	LLW drum rupture due to internal explosion
	Non-Design Basis
7.10	Nuclear warfare
7.11[a]	Repository breach by meteorite
7.12[a]	Repository breach by drilling
7.13[a]	Repository breach by solution mining
7.14	Volcanism
7.15[a]	Repository breach by faulting
7.16	Erosion
7.17	Criticality

a. Analyzed for this report.

9.3.1 Low-Level Transuranic Waste Drum Rupture Accident (Handling Error) - Accident 7.1

For this minor accident, a forklift operator error is assumed to result in the breach of one drum of low-level transuranic waste. The accident can occur in the surface facility or in the low-level waste mine and has an estimated frequency of 0.15/yr. For the 0.63 MTHM equivalent contained in a single drum, a release fraction of 2.5×10^{-5} over a release time of 30 min was used.

Radioactive materials that would be released to the outside environment from this accident are presented in Table 9.3-2. The releases are assumed to be the same whether the accident occurs in the surface facility or the low-level waste mine.

TABLE 9.3-2. Radioactive Material Released to the Atmosphere from a Low-Level Transuranic Waste Accident at the Geologic Repository for LWR Reprocessing Wastes, Ci

Nuclide	U and Pu Recycle	U Recycle Only
^{3}H	6.3×10^{-6}	6.3×10^{-6}
^{14}C	1.6×10^{-10}	1.6×10^{-10}
^{60}Co	6.2×10^{-13}	6.2×10^{-13}
^{90}Sr	9.2×10^{-13}	9.8×10^{-13}
^{95}Zr	5.1×10^{-12}	5.1×10^{-12}
^{95}Nb	1.1×10^{-11}	1.1×10^{-11}
^{106}Ru	2.8×10^{-10}	2.6×10^{-10}
^{129}I	1.6×10^{-9}	1.5×10^{-9}
^{134}Cs	1.8×10^{-12}	1.8×10^{-12}
^{137}Cs	1.4×10^{-12}	1.4×10^{-12}
^{238}Pu	8.2×10^{-12}	4.6×10^{-12}
^{239}Pu	5.4×10^{-13}	4.4×10^{-13}
^{240}Pu	1.1×10^{-12}	6.8×10^{-13}
^{241}Pu	2.7×10^{-10}	1.6×10^{-10}

Based on the releases listed in Table 9.3-2, the 70-year dose commitment to the maximum individual was calculated and is presented in Table 9.3-3. Doses will be the same whether the accident occurs in the surface facility or mine since all releases will be from the same 120-m mine exhaust stack.

TABLE 9.3-3. 70-Year Dose Commitment to the Maximum Individual from a Low-Level Transuranic Waste Drum Rupture Accident at the Geologic Repository for LWR Reprocessing Wastes, rem

Pathway	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle		
Air submersion	6.4×10^{-18}	6.4×10^{-18}	6.4×10^{-18}	6.4×10^{-18}
Inhalation	1.9×10^{-13}	1.0×10^{-12}	6.8×10^{-13}	2.1×10^{-12}
Ingestion	8.1×10^{-13}	2.2×10^{-10}	5.3×10^{-13}	1.3×10^{-13}
Total	1.0×10^{-12}	2.2×10^{-10}	1.2×10^{-12}	2.2×10^{-12}
		U Recycle Only		
Air submersion	6.0×10^{-18}	6.0×10^{-18}	6.0×10^{-18}	6.0×10^{-18}
Inhalation	1.5×10^{-13}	9.7×10^{-13}	4.6×10^{-13}	1.3×10^{-12}
Ingestion	7.9×10^{-13}	2.0×10^{-10}	5.3×10^{-13}	1.2×10^{-13}
Total	9.4×10^{-13}	2.0×10^{-10}	9.9×10^{-13}	1.4×10^{-12}

The 70-year total-body dose to the maximum individual would be 1.0×10^{-12} rem and 9.4×10^{-13} rem for the uranium and plutonium recycle and uranium recycle-only options, respectively. For the same period the maximum individual would receive about 7.0 rem from naturally occurring sources.

The 70-year worldwide population dose would be approximately 3.9×10^{-18} man-rem compared with 4.5×10^{10} man-rem received from naturally occurring sources.

9.3.2 Canister Drop Down Mine Shaft - Salt Repository For Reprocessing Waste - (DOE/ET-0028 - Accident 7.6)

For the canister drop down mine shaft accident, the canistered waste is assumed to be released to the mine atmosphere from four failed canisters in a time period of 1 hr. Canistered waste will be one of three forms:

- Solidified High-Level Wastes:
  - Glass (175 kg/MTHM) - 13 kg of particles less than 10 μm in diameter will be released to mine filters. Postulated frequency of occurrence is 7×10^{-7}/yr.
  - Calcine (52.5 kg/MTHM) - 31 kg of particles less than 10 μm will be released to mine filters. Frequency of occurrence is 7×10^{-7}/yr.
- Fuel Residue Wastes - 1.3 kg of zircaloy fines less than 10 μm in diameter will reach the mine filters. The postulated frequency of occurrence is 2×10^{-6}/yr.
- Solid Intermediate-Level Wastes - 150 kg of particles will be released to the mine filters (particles are less than 10 μm in diameter). Postulated frequency for this accident is 2×10^{-5}/yr.
- Low-Level Waste - Rupture of 12 drums resulting in the release of 1×10^{-3} hg equivalent of solidified intermediate-level waste. The postulated frequency for this accident is 3×10^{-6}/yr.

The radioactive materials that would be released to the outside environment for the various waste forms are presented in Tables 9.3-4 through 9.3-7. These releases were determined assuming that material released in the mine shaft passes through a roughing filter and two HEPA filters (DF of 10^7) prior to escaping to the environment through the 110-m stack. Based on these releases, the dose commitments to the maximum individual were calculated and are presented in Tables 9.3-8 through 9.3-11.

The canister drop of solidified high-level waste would be the worst case postulated for this series of accidents. Doses to the maximum individual would be approximately a factor of 10 higher for the canister drop of calcined high-level wastes than for the vitrified high-level waste (glass). The 70-year total body dose commitment to the maximum individual for the calcined waste drop would be negligible ($<1.0 \times 10^{-6}$ rem/yr total body dose). Maximum individual doses from the fuel residue waste canister drop and intermediate-level waste canister drop would be from 10-250 times lower than the maximum doses from the solidified HLW canister drop.

TABLE 9.3-4. Accident Release Inventory for Solidified High-Level Waste (Glass) Canister Drop Down Mine Shaft at Salt Repository for Reprocessing Wastes, Ci

Nuclide	U & Pu Recycle	U Recycle Only, Pu in Waste	U Recycle Only, Pu in PuO_2 Storage
^{90}Y	3.9×10^{-4}	4.4×10^{-4}	4.4×10^{-4}
^{90}Sr	3.9×10^{-4}	4.4×10^{-4}	4.4×10^{-4}
^{106}Ru	4.4×10^{-5}	3.8×10^{-5}	3.8×10^{-5}
^{125m}Te	4.8×10^{-6}	4.4×10^{-6}	4.4×10^{-6}
^{134}Cs	8.0×10^{-5}	1.6×10^{-4}	1.6×10^{-4}
^{137}Cs	6.0×10^{-4}	6.0×10^{-4}	6.0×10^{-4}
^{144}Ce	2.0×10^{-5}	2.1×10^{-5}	2.1×10^{-5}
^{154}Eu	3.6×10^{-5}	3.2×10^{-5}	3.2×10^{-5}
^{238}Pu	5.6×10^{-7}	2.2×10^{-5}	2.4×10^{-7}
^{239}Pu	1.3×10^{-8}	2.1×10^{-6}	1.1×10^{-8}
^{240}Pu	5.2×10^{-8}	3.3×10^{-5}	2.0×10^{-8}
^{241}Pu	6.4×10^{-6}	6.0×10^{-4}	3.1×10^{-6}
^{241}Am	5.2×10^{-6}	8.0×10^{-6}	2.7×10^{-6}
^{244}Cm	4.4×10^{-5}	7.2×10^{-6}	7.2×10^{-5}

TABLE 9.3-5. Accident Release Inventory for Solidified High-Level Waste (Calcine) Canister Drop Down Mine Shaft at Salt Repository for Reprocessing Wastes, Ci

Nuclide	U & Pu Recycle	U Recycle Only, Pu in Waste	U Recycle Only, Pu in PuO_2 Storage
^{90}Y	3.2×10^{-3}	3.4×10^{-3}	3.4×10^{-3}
^{90}Sr	3.2×10^{-3}	3.4×10^{-3}	3.4×10^{-3}
^{106}Ru	3.4×10^{-4}	3.1×10^{-4}	3.1×10^{-4}
^{125m}Te	4.0×10^{-5}	3.5×10^{-5}	3.5×10^{-5}
^{134}Cs	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
^{137}Cs	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}
^{144}Ce	1.6×10^{-4}	1.7×10^{-4}	1.7×10^{-4}
^{154}Eu	2.8×10^{-4}	2.6×10^{-4}	2.6×10^{-4}
^{238}Pu	4.4×10^{-6}	1.8×10^{-4}	1.9×10^{-6}
^{239}Pu	1.0×10^{-7}	1.7×10^{-5}	8.8×10^{-8}
^{240}Pu	4.0×10^{-7}	2.6×10^{-5}	1.6×10^{-7}
^{241}Pu	4.0×10^{-5}	4.8×10^{-3}	2.5×10^{-5}
^{241}Am	4.0×10^{-5}	6.4×10^{-5}	2.2×10^{-5}
^{244}Cm	3.5×10^{-4}	6.0×10^{-5}	6.0×10^{-5}

TABLE 9.3-6. Accident Release Inventory for Fuel Residue Waste Canister Drop Down Mine Shaft at Salt Repository for Reprocessing Waste, Ci

Nuclide	U & Pu Recycle	U Recycle Only[a]
^{3}H	2.5×10^{-1}	2.5×10^{-1}
^{14}C	4.4×10^{-4}	4.4×10^{-4}
^{60}Co	1.6×10^{-6}	1.6×10^{-6}
^{63}Ni	1.6×10^{-7}	1.6×10^{-7}
^{90}Sr	1.2×10^{-8}	1.3×10^{-8}
^{54}Mn	8.1×10^{-8}	8.1×10^{-8}
^{95}Nb	8.2×10^{-8}	8.2×10^{-8}
^{137}Cs	1.9×10^{-8}	1.8×10^{-8}
^{144}Ce	4.8×10^{-8}	5.0×10^{-8}
^{238}Pu	1.1×10^{-9}	6.2×10^{-10}
^{239}Pu	7.2×10^{-11}	5.8×10^{-11}
^{240}Pu	1.5×10^{-10}	9.0×10^{-11}
^{241}Pu	3.6×10^{-8}	2.2×10^{-8}
^{241}Am	1.4×10^{-10}	7.4×10^{-11}
^{242}Cm	2.0×10^{-9}	7.0×10^{-10}
^{244}Cm	1.4×10^{-9}	2.4×10^{-10}

a. Releases are considered to be the same whether Pu is in waste or in PuO_2 storage.

TABLE 9.3-7. Accident Release Inventory for an Intermediate-Level Waste Canister Drop Down Mine Shaft at Salt Repository for Reprocessing Wastes, Ci

Nuclide	U & Pu Recycle	U Recycle Only[a]
^{3}H	5.9×10^{-2}	5.9×10^{-2}
^{90}Sr	8.5×10^{-9}	9.1×10^{-9}
^{95}Zr	4.8×10^{-8}	4.8×10^{-8}
^{95}Nb	1.1×10^{-7}	1.1×10^{-7}
^{106}Ru	2.7×10^{-6}	2.4×10^{-6}
^{129}I	1.5×10^{-5}	1.4×10^{-5}
^{134}Cs	1.7×10^{-8}	1.7×10^{-8}
^{137}Cs	1.3×10^{-8}	1.3×10^{-8}
^{238}Pu	7.7×10^{-8}	4.3×10^{-8}
^{239}Pu	5.0×10^{-9}	4.1×10^{-9}
^{240}Pu	1.0×10^{-8}	6.3×10^{-9}
^{241}Pu	2.5×10^{-6}	1.5×10^{-6}
^{241}Am	9.9×10^{-9}	3.0×10^{-8}
^{242}Cm	1.4×10^{-7}	4.9×10^{-8}
^{244}Cm	1.0×10^{-7}	1.7×10^{-8}

a. Releases are considered to be the same whether Pu is in the waste or in PuO_2 storage.

TABLE 9.3-8. 70-Year Dose Commitment to Maximum Individual[a] from Solid High-Level Waste (Glass) Canister Drop Down Mine Shaft at a Salt Repository for Reprocessing Wastes, rem

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle			
Air submersion	4.0×10^{-9}	2.0×10^{-9}	2.0×10^{-9}	2.0×10^{-9}	2.0×10^{-9}
Inhalation		1.4×10^{-5}	1.0×10^{-8}	1.3×10^{-4}	1.6×10^{-4}
Total	4.0×10^{-9}	1.4×10^{-5}	1.2×10^{-8}	1.3×10^{-4}	1.6×10^{-4}
		U Recycle - Pu in Waste			
Air submersion	4.0×10^{-9}	1.9×10^{-9}	1.9×10^{-9}	1.9×10^{-9}	1.9×10^{-9}
Inhalation		5.5×10^{-6}	1.0×10^{-8}	1.1×10^{-4}	3.4×10^{-4}
Total	4.0×10^{-9}	5.5×10^{-6}	1.2×10^{-8}	1.1×10^{-4}	3.4×10^{-4}
		U Recycle - Pu in PuO_2 Storage			
Air submersion	4.0×10^{-9}	1.9×10^{-9}	1.9×10^{-9}	1.1×10^{-9}	1.9×10^{-9}
Inhalation		8.0×10^{-6}	9.2×10^{-9}	3.6×10^{-5}	5.6×10^{-5}
Total	4.0×10^{-9}	8.0×10^{-6}	1.1×10^{-8}	3.6×10^{-5}	5.6×10^{-5}

a. The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time integrated atmospheric dispersion coefficient (E/Q) of 1.3×10^{-5} sec/m^3.

TABLE 9.3-9. 70-Year Dose Commitment to Maximum Individual[a] from Solidified High-Level Waste (Calcine) Canister Drop Down Mine Shaft at a Salt Repository for Reprocessing Wastes, rem

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle			
Air submersion	3.2×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	1.6×10^{-8}
Inhalation		1.2×10^{-4}	8.4×10^{-8}	1.0×10^{-3}	1.3×10^{-3}
Total	3.2×10^{-8}	1.2×10^{-4}	1.0×10^{-7}	1.0×10^{-3}	1.3×10^{-3}
		U Recycle - Pu in Waste			
Air submersion	3.3×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	1.6×10^{-8}
Inhalation		1.8×10^{-4}	7.2×10^{-8}	9.2×10^{-4}	2.8×10^{-3}
Total	3.3×10^{-8}	1.8×10^{-4}	8.8×10^{-8}	9.2×10^{-4}	2.8×10^{-3}
		U Recycle - Pu in PuO_2 Storage			
Air submersion	3.3×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	1.6×10^{-8}
Inhalation		6.4×10^{-5}	7.2×10^{-8}	2.9×10^{-4}	4.8×10^{-4}
Total	3.3×10^{-8}	6.4×10^{-5}	8.8×10^{-8}	2.9×10^{-4}	4.8×10^{-4}

a. The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time integrated atmospheric dispersion coefficient (E/Q) of 1.3×10^{-5} sec/m^3.

TABLE 9.3-10. 70-Year Dose Commitment to Maximum Individual[a] from Fuel Residue Waste Canister Drop Down Mine Shaft at Salt Repository for Reprocessing Wastes, rem

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle			
Air submersion	2.0×10^{-11}	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}
Inhalation		1.7×10^{-7}	1.7×10^{-7}	2.1×10^{-7}	2.2×10^{-8}
Total	2.0×10^{-11}	1.7×10^{-7}	1.7×10^{-7}	2.1×10^{-7}	2.2×10^{-8}
		U Recycle Only			
Air submersion	2.0×10^{-11}	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}
Inhalation		1.7×10^{-7}	1.7×10^{-7}	2.0×10^{-7}	1.3×10^{-8}
Total	2.0×10^{-11}	1.7×10^{-7}	1.7×10^{-7}	2.0×10^{-7}	1.3×10^{-8}

a. The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time integrated atmospheric dispersion coefficient (E/Q) of 1.3×10^{-5} sec/m^3.

TABLE 9.3-11. 70-Year Dose Commitment to Maximum Individual[a] from Intermediate-Level Waste Canister Drop Down Mine Shaft at Salt Repository for Reprocessing Wastes, rem

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U and Pu Recycle			
Air submersion	1.3×10^{-11}	1.8×10^{-12}	1.8×10^{-12}	1.8×10^{-12}	1.8×10^{-12}
Inhalation		1.4×10^{-7}	4.6×10^{-7}	6.5×10^{-7}	1.3×10^{-6}
Total	1.3×10^{-11}	1.4×10^{-7}	4.6×10^{-7}	6.5×10^{-7}	1.3×10^{-6}
		U Recycle Only			
Air submersion	1.2×10^{-11}	1.7×10^{-12}	1.6×10^{-12}	1.7×10^{-12}	1.7×10^{-12}
Inhalation		6.9×10^{-8}	4.3×10^{-7}	2.7×10^{-7}	6.1×10^{-7}
Total	1.2×10^{-11}	6.9×10^{-8}	4.3×10^{-7}	2.7×10^{-7}	6.1×10^{-7}

a. The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time integrated atmospheric dispersion coefficient (E/Q) of 1.3×10^{-5} sec/m^3.

The 70-year worldwide population dose commitment would be greatest for the fuel residue waste canister drop (3.0×10^{-1} man-rem compared with 4.5×10^{10} man-rem from naturally occurring sources for the same period). Doses from a drop of 12 LLW drums would be on the order of 1×10^{-3} of those given in Table 9.3-11.

9.3.3 Repository Breach by Meteorite Impact - Accident 7.11

Breach of the repository by a meteorite impact (non-design basis accident) would be caused only by a meteorite striking the surface above the repository area with sufficient mass and velocity to cause a crater with a depth of about 600 m. Based on a 3:1 ratio of crater diameter to depth for large meteorites, a crater approximately 600 m deep would be expected to have a

diameter of about 2 km. The probability that a large meteorite would strike the surface over the repository area and produce a crater 2 km in diameter is 2×10^{-7} over a 1-million-yr period or 2×10^{-13}/yr.[2]

Most large meteorites are composed of iron or nickel and iron with a density of about 8 g/cm^3. Assuming an impact velocity of 20 km/sec and the 3:1 ratio of crater diameter to depth, a meteorite of at least 7×10^7 kg (about 25 m in diameter) would be required to form a crater 600 m deep. The kinetic energy of such a meteorite would be equivalent to that from about 3.5 million tons of TNT.

9.3.3.1 Nonradiological Effects

Temperatures at the point of impact would reach millions of degrees, and most of the meteorite plus some of the surrounding rock would be vaporized. Some of the rock material would be pulverized and ejected into the air during formation of the crater. Most of the ejected material would be expected to fall back into the crater and its immediate vicinity. A small fraction of the waste contained in the repository would probably be ejected.

Physical and thermal effects of a meteorite strike at the geologic repository have been extrapolated from the effects expected from a 3.5-MT nuclear explosion above ground. Several factors must be considered in making this extrapolation since the amount of initial energy from the meteorite that will be converted to air blast (shockwave), ground shock, and thermal energy is not known. About 50% of the energy from a nuclear explosion is converted to air blast and ground shock and about 35% is converted to thermal energy;[3] about 100% of the energy from a TNT explosion is converted to air blast and ground shock with minimal conversion to thermal energy.[3] Therefore, if the effects of a meteorite strike are extrapolated from the effects of a 3.5-MT nuclear explosion and the meteorite strike actually more closely resembles a 3.5-MT TNT blast, physical effects from air blast and ground shock could be underestimated by a factor of 2. Thermal effects could be considerably overestimated from the same extrapolation.

The major physical damage from a meteorite impact will be caused by air blast energy from the impact. Energy will also be spent in producing a crater and shock (or pressure) waves in the ground. Table 9.3-12 presents predicted damage from the meteorite strike for selected structures and objects at various distances from the point of impact. Structural damage would be light beyond 16 km from the point of impact. Between 3.2 km and 16 km, damage would increase steadily until complete destruction (Type A) would be expected within 3.2 km from impact. One exception would be the blast-resistant, reinforced-concrete, windowless buildings. These buildings would not be expected to undergo Type A destruction unless located within 1.6 km from the point of impact.

Maximum predictable thermal effects would be skin burns and ignition of flammable materials within 20 km of the impact. Actual thermal effects are expected to be limited to a smaller area. Maximum skin effects might be:

Burn Type	Distance, km
Third degree	12
Second degree	14
First degree	20

TABLE 9.3-12. Predicted Structural Damage Caused by a Meteorite Strike (crater 2 km in diameter) at a Geologic Repository for Spent Fuel(3)

Distance from Point of Impact, km	Blast-Resistant, Reinforced-Concrete Windowless Building	Multistory Building, Brick Apartment House	Wood Frame House	Heavy Steel Frame Industrial (1 Story, Light Walls)	Motorized Vehicles	Forests (400 trees/ha)
80						
32		D	D	D		
16		D	D	D		G
8		C	B	C	D	F
3	C	A	A	A	A	E
<1.6	A	A	A	A	A	E

Key:

Type A - virtually complete destruction.
Type B - destruction severe enough to need very extensive (perhaps prohibitive) repair.
Type C - would require major repairs before the object or structure could be used for its intended purpose.
Type D - would involve minor repairs or could be used without repairs.
Type E - up to 90% of trees down; remainder denuded of branches and leaves.
Type F - about 30% of trees down; remainder have some branches and leaves blown off.
Type G - few trees down; some leaves and branches blown off.

Maximum thermal energy received might be:

Thermal Energy, cal/cm^2	Distance, km
12	19
8	22
5	27
3	35

Effects of these thermal energies can be related to the following ignition energies for some common materials:

Material	Energy, cal/cm^2
Newspaper	6
Tanned leather	30
Charring of wood	10-15
Cotton shirt	13
Wool flannel	16

From this information it is evident that considerable damage from shock waves and heat would result from a large meteorite strike for a significant distance from the point of impact.

Comparison of the meteorite impact to a nuclear explosion brings up a question about release of repository inventory in the case of nuclear war. It also points up a disparity between estimates of the size of nuclear weapons capable of breaching the repository and the calculated sizes of weapons based on the kinetic energy of the meteorite. On the one hand the difference appears large; however, in the case of the meteorite, essentially all of the kinetic energy would be given up in deformation and vaporization at ground level.

Clairborne and Gera(2) state:

> The energy released in the impact (meteorite) would be on the order of several megatons of TNT, and the explosion would be similar to a nuclear blast complete with fireball, shock waves, and mushroom cloud. Temperature in the fireball would reach millions of degrees, and most of the meteorite mass would be vaporized together with some of the indigenous rocks. Some more of the geologic materials would be pulverized and thrown

> in the air, the destiny of the fine ejecta being controlled by the size of the particles and the height reached. Large particles would fall rapidly to the ground, but fine particles (submicron to a few microns) would remain airborne for significant periods. A certain amount of fine dust would be injected into the stratosphere and, in turn, would achieve worldwide distribution. However, the observation of young impact craters shows that by far the greatest part of the ejected material would fall back inside the crater and its immediate vicinity to form the crater rim and fill.

On the other hand, their remarks on nuclear warfare suggest that much larger releases of energy from nuclear weapons would not breach the reference repository:

> Current nuclear weapons are of such size that a surface burst would penetrate a sealed repository no deeper than 500 m. The largest deployed missile is reported to be capable of carrying a 25-megaton warhead. Using the information given by Glasstone, a surface burst of this magnitude would generate a 270 m deep crater with a fracture zone down to about 400 m in a geologic material with the physical properties of dry soil. The crater would be somewhat smaller in salt. Assuming the development of a 50 megaton weapon, the potential crater depth in dry soil would increase to only 340 m and the fracture zone to 500 m. Since the waste horizon will be about 600 m below the surface, the containment would not be breached even for the larger weapon.*

9.3.4 Radiological Effects

The amount of waste released in the event of a meteorite impact would depend on the amount of waste in an individual repository. In this LWR scenario, the number of repositories depends on the geologic medium in which the repository is constructed. The number of repositories required for waste disposal in the fuel reprocessing option are:

Recycle Mode	Salt	Granite	Shale	Basalt
U and Pu Recycle	6	7	10	6
U-only Recycle, Pu in HLW	10	6	10	6
U-only Recycle, PuO_2 stored	5	5	10	6

Different numbers of repositories are required because of differences in the design thermal loading for the host rock and in the degree to which the reference 800-ha underground cavity may be used for waste disposal. (Larger supporting columns are required in salt than in granite. Thus, a repository in granite of the same overall area could contain a greater amount of waste.)

In this analysis no account is made of differences in release of waste that may result from a meteorite impacting on different rock (although some differences may be expected between sedimentary and igneous rock). The disposal concept likely to be put in place may employ repositories in several media. There is apparently no engineering reason for not having the same amount of waste in each repository; the overall area would then be a variable rather than a constant. Separation of wastes for placement in different repositories is not now contemplated; therefore, the relative abundance of individual radionuclides will remain the same regardless of the number of repositories among which the waste is distributed. The consequences of a meteorite

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* Note that the reference repository is located at a beginning depth of 525 m rather than 600 m.

strike were calculated based on the wastes in a repository that were generated by reprocessing 50,000 MTHM equivalent. The consequences of a meteorite impacting a repository in any of the four media of interest can be determined by multiplying the tabulated consequences by the factors presented in Table 9.3-13.*

TABLE 9.3-13. Factors for Changing Consequences that are Presented in Tables 9.3-17 through 9.3-29 for 50,000-MTHM Repository to Factors for Repositories Based on Fuel Cycle and Reference Repository by Medium

Medium	U and Pu Recycle	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2
Salt	1.3	0.8	1.5
Granite	1.1	1.3	1.5
Shale	0.8	0.8	0.8
Basalt	1.3	1.3	1.3

At a penetration depth of 600 m, it is assumed that the meteorite impact would result in dispersion of 1% of the 50,000-MTHM equivalent repository inventory. The amounts of various radionuclides ejected depend on the length of time between repository closure and meteorite impact. This event is characterized for a strike in the year 2050 (assumed time of repository closure and maximum inventory) and for 1000, 100,000 or 1,000,000 years thereafter in Tables 9.3-14 through 9.3-16.

On the basis of nuclear crater test results, dispersion of radioactive material suspended from a meteorite impact would occur by two modes. Typical cloud formation consists of a central column rising about a doughnut-shaped (torus) base surge, which rolls outward from the crater. It is assumed that one-half of the suspended material is dispersed in the central column and one-half is dispersed in the base cloud. The material in the central cloud is also assumed to be dispersed evenly across the eastern half of the United States and then to move around the world at a high altitude. Compared to the base cloud, the central cloud would not contribute significantly to local (radius of 80 km) fallout. Large over-pressures in air produced on impact of the meteorite are assumed to override any local low-altitude winds.

For particulates (all but ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I are assumed to be in particulate form), the source term for this accident, which is 1% of the repository inventory, is multiplied by 0.1 because it is assumed that only 10% of the particulates suspended are of respirable size. The remaining 90% of the material is assumed to immediately fall back into or near the crater and not contribute to resulting doses to the regional population. For the regional population the source term is also reduced by one-half to account for the distribution of material between central and base clouds.

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* Developing the consequences for breach of a single 50,000-MTHM repository obviates the need for 12 tables (the values of which do not differ by more than a factor of 2) for each dose calculation because of different geologic media in which waste may be isolated or fuel cycle chosen.

TABLE 9.3-14. Radionuclides that would be Released from Breach by Meteorite of a 50,000-MTHM Equivalent Repository Containing U Recycle - Pu Stored in SHLW, Ci

Nuclide	At Closure	+1000 yr	+100,000 yr	+1,000,000 yr
^{3}H	2.2×10^{3}	---	---	---
^{14}C	2.7×10^{1}	2.4×10^{1}	1.5×10^{-4}	---
^{60}Co	2.6×10^{3}	---	---	---
^{90}Sr	6.6×10^{5}	8.6×10^{-5}	---	---
^{99}Tc	3.2×10^{2}	3.2×10^{2}	2.2×10^{2}	1.2×10^{1}
^{125m}Te	1.4×10^{2}	---	---	---
^{129}I	7.9	7.9	7.9	7.9
^{137}Cs	9.4×10^{5}	5.1×10^{-4}	---	---
^{154}Eu	2.9×10^{4}	---	---	---
^{226}Ra	---	---	---	3.5
^{238}Pu	8.6×10^{4}	---	---	---
^{239}Np	---	2.9×10^{2}	3.4×10^{1}	---
^{239}Pu	7.3×10^{3}	7.3×10^{3}	4.4×10^{2}	4.0×10^{-7}
^{240}Pu	1.1×10^{4}	9.9×10^{3}	---	---
^{241}Pu	5.1×10^{5}	---	---	---
^{241}Am	7.9×10^{4}	2.2×10^{4}	---	---
^{244}Cm	7.3×10^{3}	---	---	---

TABLE 9.3-15. Radionuclides that would be Released from Breach by Meteorite of a 50,000-MTHM Equivalent Repository Containing U Recycle - Pu Stored as PuO_2, Ci

Nuclide	At Closure	+1000 yr	+100,000 yr	+1,000,000 yr
^{3}H	2.2×10^{3}	---	---	---
^{14}C	2.7×10^{1}	2.4×10^{1}	1.5×10^{5}	---
^{60}Co	2.6×10^{3}	---	---	---
^{90}Sr	6.6×10^{5}	8.6×10^{-5}	---	---
^{99}Tc	3.2×10^{2}	3.2×10^{2}	2.2×10^{2}	1.2×10^{1}
^{126}Sn	---	1.1×10^{1}	5.7	---
^{129}I	7.9	7.9	7.9	7.9
^{137}Cs	9.2×10^{5}	5.1×10^{-5}	---	---
^{154}Eu	2.9×10^{4}	---	---	---
^{233}U	---	---	6.5	1.5×10^{1}
^{237}Np	---	1.8×10^{1}	1.8×10^{1}	1.4×10^{1}
^{238}Pu	8.6×10^{2}	---	---	---
^{239}Np	---	2.9×10^{2}	---	---
^{239}Pu	6.6×10^{1}	7.3×10^{1}	1.3×10^{1}	1.1×10^{-8}
^{240}Pu	---	1.6×10^{2}	---	---
^{241}Am	1.5×10^{4}	3.4×10^{3}	---	---
^{244}Cm	7.3×10^{3}	---	---	---

TABLE 9.3-16. Radionuclides that would be Released from Breach by Meteorite of a 50,000-MTHM Equivalent Repository Containing U and Pu Recycle Wastes, Ci

Nuclide	At Closure	+1000 yr	+100,000 yr	+1,000,000 yr
^{3}H	2.3×10^{3}	---	---	---
^{14}C	2.6×10^{1}	2.3×10^{1}	1.5×10^{-5}	---
^{60}Co	2.5×10^{3}	---	---	---
^{90}Sr	5.8×10^{5}	7.3×10^{-5}	---	---
^{99}Tc	3.1×10^{2}	3.1×10^{2}	2.3×10^{2}	1.2×10^{1}
^{126}Sn	1.4×10^{1}	1.4×10^{1}	6.6	---
^{129}I	8.6	8.6	8.6	8.6
^{137}Cs	9.2×10^{5}	5.1×10^{-5}	---	---
^{154}Eu	3.6×10^{4}	---	---	---
^{229}Th	---	---	7.9	1.9×10^{1}
^{233}U	---	---	7.3	---
^{237}Np	---	---	2.1×10^{1}	1.6×10^{1}
^{238}Pu	2.0×10^{3}	7.3×10^{1}	---	---
^{239}Pu	1.1×10^{2}	1.5×10^{3}	5.3×10^{1}	5.5×10^{-8}
^{240}Pu	7.3×10^{2}	8.6×10^{2}	---	---
^{241}Am	3.6×10^{4}	8.6×10^{3}	---	---
^{244}Cm	9.2×10^{4}	---	---	---

Based on the radioactive release source terms given in Tables 9.3-14 through 9.3-16 and the methods described in Appendix B, the first-year doses to the maximum individual were calculated and are presented in Tables 9.3-17 through 9.3-19. The 70-year dose commitments to the maximum individual are presented in Tables 9.1-20 through 9.1-22.

Doses presented in Table 9.3-16 through 9.3-22 are directly proportional to the fraction of inventory released; thus, if it were postulated that 10% of the inventory was released, the reported dose would be 10 times higher than the doses presented in the tables.

The maximum individual, who is assumed to be at 4 km from point of impact, is believed to have only a small chance of surviving the initial blast of the meteorite. Regardless, doses in the first year following a release of wastes in the year 2050 would amount to 8700 rem and would be expected to be fatal.

The number of persons in the reference environment who would be expected to receive at least 500 rem the first year was estimated. The estimate was made by calculating the ratio of the atmospheric dispersion coefficients at various points of the compass to the distance from the point of contact. The number of persons so exposed amounted to about 30,000. If it is assumed that this 500-rem dose is received in a short time, it would prove fatal to essentially all of the individuals.

TABLE 9.3-17. First-Year Doses to the Maximum Individual from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM, for Various Times After Closure - U Recycle - Pu in SHLW, rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.7×10^{-2}	1.7×10^{-2}	1.7×10^{-2}	1.7×10^{-2}
Inhalation	1.8×10^{1}	4.5×10^{-3}	1.7×10^{3}	2.7×10^{2}
Ingestion	6.3×10^{3}	3.8×10^{2}	5.0×10^{2}	1.5×10^{4}
External	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}
Total	8.7×10^{3}	2.8×10^{3}	4.6×10^{3}	1.8×10^{4}
		+1000 yr		
Air submersion	2.3×10^{-5}	2.3×10^{-5}	2.3×10^{-5}	2.3×10^{-5}
Inhalation	2.6	$1 8 \times 10^{-3}$	3.4×10^{2}	4.3×10^{1}
Ingestion	1.3	3.8×10^{2}	2.6×10^{-3}	1.4×10^{1}
External	2.5	2.5	2.5	2.5
Total	6.4	3.8×10^{2}	3.4×10^{2}	6.0×10^{1}
		+100,000 yr		
Air submersion	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation	4.4×10^{-2}	1.8×10^{-3}	5.5	8.6×10^{-1}
Ingestion	3.9	3.8×10^{2}	6.5×10^{-4}	5.1
External	2.4×10^{-1}	2.4×10^{-1}	2.4×10^{-1}	2.4×10^{-1}
Total	4.2	3.8×10^{2}	5.7	6.2
		+1,000,000 yr		
Air submersion	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}
Inhalation	1.6×10^{-2}	1.7×10^{-3}	1.9	3.0×10^{-1}
Ingestion	1.1	3.6×10^{2}	3.4×10^{-5}	1.5
External	1.2×10^{-1}	1.2×10^{-1}	1.2×10^{-1}	1.2×10^{-1}
Total	1.2	3.6×10^{2}	2.0	1.9

TABLE 9.3-18. First-Year Doses to the Maximum Individual from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM, for Various Times After Closure - U Recycle - Pu Stored as PuO_2, rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
Inhalation	6.6	4.5×10^{-3}	2.7×10^{2}	4.0×10^{1}
Ingestion	6.3×10^{3}	3.8×10^{2}	5.0×10^{2}	1.5×10^{4}
External	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}
Total	8.7×10^{3}	2.8×10^{3}	3.2×10^{3}	1.7×10^{4}
		+1000 yr		
Air submersion	3.6×10^{-6}	3.6×10^{-6}	3.6×10^{-6}	3.6×10^{-6}
Inhalation	2.6×10^{-1}	1.8×10^{-3}	3.4×10^{1}	3.4
Ingestion	5.9×10^{-1}	3.8×10^{2}	3.6×10^{-3}	1.7
External	7.9×10^{-1}	7.9×10^{-1}	7.9×10^{-1}	7.9×10^{-1}
Total	1.1	3.8×10^{2}	3.5×10^{1}	5.9
		+100,000 yr		
Air submersion	4.2×10^{-7}	4.2×10^{-7}	4.2×10^{-7}	4.2×10^{-7}
Inhalation	4.8×10^{-3}	1.8×10^{-3}	5.9×10^{-1}	9.9×10^{-2}
Ingestion	5.6×10^{-1}	3.8×10^{2}	6.6×10^{-4}	4.6×10^{-1}
External	7.9×10^{-2}	7.9×10^{-2}	7.9×10^{-2}	7.9×10^{-2}
Total	6.4×10^{-1}	3.8×10^{2}	6.7×10^{-1}	6.4×10^{-1}
		+1,000,000 yr		
Air submersion	8.6×10^{-8}	8.6×10^{-8}	8.6×10^{-8}	8.6×10^{-8}
Inhalation	7.9×10^{-3}	1.7×10^{-3}	9.2×10^{-1}	1.5×10^{-1}
Ingestion	4.8×10^{-1}	3.6×10^{2}	5.1×10^{-4}	4.9×10^{-1}
External	5.9×10^{-2}	5.9×10^{-2}	5.9×10^{-2}	5.9×10^{-2}
Total	5.5×10^{-1}	3.6×10^{2}	9.8×10^{-1}	7.0×10^{-1}

TABLE 9.3-19. First-Year Doses to the Maximum Individual from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM, for Various Times After Closure - U and Pu Recycle, rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
Inhalation	1.4×10^{1}	5.3×10^{-3}	1.3×10^{3}	1.5×10^{2}
Ingestion	5.9×10^{3}	4.1×10^{2}	5.1×10^{2}	1.3×10^{4}
External	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}
Total	8.3×10^{3}	2.8×10^{3}	4.2×10^{3}	1.5×10^{4}
		+1000 yr		
Air submersion	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}
Inhalation	7.9×10^{-1}	1.9×10^{-3}	9.9×10^{1}	9.9
Ingestion	8.6×10^{-1}	4.1×10^{2}	3.5×10^{-3}	4.4
External	3.1	3.1	3.1	3.1
Total	4.8	4.1×10^{2}	1.0×10^{1}	1.7×10^{1}
		+100,000 yr		
Air submersion	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-7}
Inhalation	7.9×10^{-3}	1.9×10^{-3}	9.9×10^{-1}	1.7×10^{-1}
Ingestion	7.3×10^{-1}	4.1×10^{2}	6.6×10^{-4}	6.3×10^{-1}
External	9.2×10^{-2}	9.2×10^{-2}	9.2×10^{-2}	9.2×10^{-2}
Total	8.3×10^{-1}	4.1×10^{2}	1.1	8.9×10^{-1}
		+1,000,000 yr		
Air submersion	9.9×10^{-8}	9.9×10^{-8}	9.9×10^{-8}	9.9×10^{-8}
Inhalation	8.6×10^{-3}	1.8×10^{-3}	1.1	1.7×10^{-1}
Ingestion	5.2×10^{-1}	3.9×10^{2}	6.3×10^{-4}	5.4×10^{-1}
External	6.6×10^{-2}	6.6×10^{-2}	6.6×10^{-2}	6.6×10^{-2}
Total	5.9×10^{-1}	3.9×10^{2}	1.2	7.8×10^{1}

TABLE 9.3-20. 70-Year Dose Commitment to the Maximum Individual from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM, for Various Times After Closure - U Recycle Pu in SHLW, rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
Inhalation	6.4×10^{2}	4.7×10^{-3}	4.1×10^{3}	1.1×10^{4}
Ingestion	3.9×10^{6}	9.2×10^{2}	1.5×10^{3}	1.6×10^{7}
External	1.6×10^{5}	1.6×10^{5}	1.6×10^{5}	1.6×10^{5}
Total	4.1×10^{6}	1.6×10^{5}	1.7×10^{5}	1.6×10^{7}
		+1000 yr		
Air submersion	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}
Inhalation	1.2×10^{2}	2.1×10^{-3}	8.6×10^{2}	2.1×10^{3}
Ingestion	7.9×10^{1}	9.2×10^{2}	8.6×10^{-7}	1.8×10^{3}
External	1.7×10^{2}	1.7×10^{2}	1.7×10^{2}	1.7×10^{2}
Total	3.7×10^{2}	1.1×10^{3}	1.0×10^{3}	4.1×10^{3}
		+100,000 yr		
Air submersion	5.3×10^{-7}	5.3×10^{-7}	5.3×10^{-7}	5.3×10^{-7}
Inhalation	2.2	2.1×10^{-3}	1.4×10^{1}	4.3×10^{1}
Ingestion	2.9×10^{2}	9.2×10^{2}	2.2×10^{-2}	7.9×10^{2}
External	1.6×10^{1}	1.6×10^{1}	1.6×10^{1}	1.6×10^{1}
Total	3.1×10^{2}	9.4×10^{2}	3.0×10^{1}	8.5×10^{2}
		+1,000,000 yr		
Air submersion	1.6×10^{-7}	1.6×10^{-7}	1.6×10^{-7}	1.6×10^{-7}
Inhalation	7.9×10^{-1}	2.0×10^{-3}	4.7	1.6×10^{1}
Ingestion	1.6×10^{2}	8.6×10^{2}	1.1×10^{-3}	4.6×10^{2}
External	1.1×10^{1}	1.1×10^{1}	1.1×10^{1}	1.1×10^{1}
Total	1.7×10^{2}	8.7×10^{2}	1.6×10^{1}	4.9×10^{2}

TABLE 9.3-21. 70-Year Dose Commitment to the Maximum Individual from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM, for Various Times After Closure - U Recycle - Pu Stored as PuO_2, rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
Inhalation	1.4×10^{2}	2.2×10^{-3}	6.5×10^{2}	1.2×10^{3}
Ingestion	3.9×10^{6}	9.2×10^{2}	1.5×10^{3}	1.6×10^{7}
External	1.6×10^{5}	1.6×10^{5}	1.6×10^{5}	1.6×10^{5}
Total	4.1×10^{6}	1.6×10^{5}	1.6×10^{5}	1.6×10^{7}
		+1000 yr		
Air submersion	3.6×10^{-6}	3.6×10^{-6}	3.6×10^{-6}	3.6×10^{-6}
Inhalation	1.1×10^{1}	2.2×10^{-3}	8.6×10^{1}	1.6×10^{2}
Ingestion	1.2×10^{1}	9.2×10^{2}	3.0×10^{-2}	1.8×10^{2}
External	5.7×10^{1}	5.7×10^{1}	5.7×10^{1}	5.7×10^{1}
Total	8.0×10^{1}	9.8×10^{2}	1.4×10^{2}	4.0×10^{2}
		+100,000 yr		
Air submersion	4.2×10^{-7}	4.2×10^{-7}	4.2×10^{-7}	4.2×10^{-7}
Inhalation	2.4×10^{-1}	2.2×10^{-3}	5.0	1.5
Ingestion	7.3	9.2×10^{2}	2.2×10^{-2}	1.8×10^{1}
External	5.5	5.5	5.5	5.5
Total	1.3×10^{1}	9.4×10^{2}	1.1×10^{1}	2.5×10^{1}
		+1,000,000 yr		
Air submersion	8.6×10^{-8}	8.6×10^{-8}	8.6×10^{-8}	8.6×10^{-8}
Inhalation	3.9×10^{-1}	2.0×10^{-3}	2.2	7.9
Ingestion	2.0	8.6×10^{2}	2.6×10^{-3}	1.8×10^{1}
External	4.2	4.2	4.2	4.2
Total	6.6	8.6×10^{2}	6.4	3.0×10^{1}

The total body-dose to the maximum individual for a breach by meteorite in the year 3050 would be about 15 times the currently acceptable annual occupational limit. Dose as a function of time of repository breach decreases slowly after the first thousand years. For a breach at 100,000 yr the dose would be about 3 times the present annual occupational limit and at one million yr the dose would be on the order of the annual occupational dose limit.

Doses to the regional population (2 million persons within 80 km) were calculated based on the radionuclide releases given in Tables 9.3-14 through 9.3-16 and the following assumptions:

- Suspended material is uniformly distributed in the cylindrical base cloud.
- The regional population is exposed to the base cloud concentration, which has been reduced by a factor of 10 for 2 hr (windspeed, $\sim$1 m/sec).

TABLE 9.3-22. 70-Year Dose Commitment to the Maximum Individual from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM, for Various Times After Closure - Uranium and Plutonium Recycle, rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
Inhalation	3.2×10^{2}	5.6×10^{-3}	3.0×10^{3}	4.2×10^{3}
Ingestion	3.4×10^{6}	9.9×10^{2}	1.6×10^{3}	1.4×10^{7}
External	1.7×10^{5}	1.7×10^{5}	1.7×10^{5}	1.7×10^{5}
Total	3.6×10^{6}	1.7×10^{5}	1.7×10^{5}	1.4×10^{7}
		+1000 yr		
Air submersion	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}
Inhalation	3.2×10^{1}	2.3×10^{-3}	2.4×10^{2}	4.9×10^{2}
Ingestion	3.2×10^{1}	9.9×10^{2}	3.0×10^{-2}	5.2×10^{2}
External	2.2×10^{2}	2.2×10^{2}	2.2×10^{2}	2.2×10^{2}
Total	2.8×10^{2}	1.2×10^{3}	4.6×10^{2}	1.2×10^{3}
		+100,000 yr		
Air submersion	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-7}
Inhalation	4.2×10^{-1}	2.2×10^{-3}	2.5	8.6
Ingestion	1.6×10^{1}	9.9×10^{2}	2.2×10^{-2}	3.4×10^{1}
External	6.6	6.6	6.6	6.6
Total	2.3×10^{1}	1.0×10^{3}	9.1	4.9×10^{1}
		+1,000,000 yr		
Air submersion	9.9×10^{-8}	9.9×10^{-8}	9.9×10^{-8}	9.9×10^{-8}
Inhalation	4.4×10^{-1}	2.2×10^{-3}	2.6	9.2
Ingestion	2.2	9.2×10^{2}	3.0×10^{-3}	2.1×10^{1}
External	4.6	4.6	4.6	4.6
Total	7.2	9.2×10^{2}	7.2	3.5×10^{1}

- The dimensions of the base cloud are 8000 m in diameter by 1200 m high.
- Deposition of material occurs for about 2.2 hr (8000 sec) at standard deposition velocities.
- About 120 days after the accident crops are planted and grown on the contaminated land.
- These crops are contaminated via root uptake and deposition of resuspended material on plant surfaces.
- The toroidal base cloud expands in a radius across the 80 km of the reference environment and all of the food consumed by the reference population is grown in the area so contaminated.

The 70-year dose commitments to the regional population are given in Tables 9.3-23 through 9.3-25.

TABLE 9.3-23. 70-Year Dose Commitment to the Regional Population from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM Equivalent, for Various Times After Closure - U Recycle - Pu Stored in SHLW, man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	2.3×10^3	2.3×10^3	2.3×10^3	2.3×10^3
Inhalation	9.2×10^7	6.6×10^2	5.5×10^8	1.5×10^9
Ingestion	2.3×10^5	2.1×10^2	3.9×10^3	9.2×10^5
External	4.1×10^1	4.1×10^1	4.1×10^1	4.1×10^1
Total	9.2×10^7	3.2×10^3	5.5×10^8	1.5×10^9
		+1000 yr		
Air submersion	2.2	2.2	2.2	2.2
Inhalation	1.7×10^7	3.0×10^2	1.2×10^8	3.0×10^8
Ingestion	2.8×10^2	2.1×10^2	1.2×10^{-1}	6.1×10^3
External	7.9×10^{-2}	7.9×10^{-2}	7.9×10^{-2}	7.9×10^{-2}
Total	1.7×10^7	5.1×10^2	1.2×10^8	3.0×10^8
		+100,000 yr		
Air submersion	7.9×10^{-2}	7.9×10^{-2}	7.9×10^{-2}	7.9×10^{-2}
Inhalation	3.0×10^5	3.0×10^2	1.9×10^6	6.0×10^6
Ingestion	6.6×10^2	2.1×10^2	1.2×10^{-3}	1.1×10^3
External	6.1×10^{-3}	6.1×10^{-3}	6.1×10^{-3}	6.1×10^{-3}
Total	3.0×10^5	5.1×10^2	1.9×10^6	6.0×10^6
		+1,000,000 yr		
Air submersion	2.2×10^{-2}	2.2×10^{-2}	2.2×10^{-2}	2.2×10^{-2}
Inhalation	1.1×10^5	2.8×10^2	6.5×10^5	2.2×10^6
Ingestion	1.2×10^2	2.0×10^2	6.1×10^{-5}	2.4×10^2
External	3.5×10^{-3}	3.5×10^{-3}	3.5×10^{-3}	3.5×10^{-3}
Total	1.1×10^5	4.8×10^2	6.5×10^5	2.2×10^6

TABLE 9.3-24. 70-Year Dose Commitment to the Regional Population from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM Equivalent, for Various Times After Closure - U Recycle - Pu Stored as PuO_2, man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	2.3×10^3	2.3×10^3	2.3×10^3	2.3×10^3
Inhalation	2.0×10^7	6.6×10^2	9.2×10^7	1.7×10^8
Ingestion	2.3×10^5	2.1×10^2	3.9×10^3	9.2×10^6
External	$4,0 \times 10^1$	4.0×10^1	4.0×10^1	4.0×10^1
Total	2.0×10^7	3.2×10^3	9.2×10^7	1.7×10^8
		+1000 yr		
Air submersion	5.1×10^{-1}	5.1×10^{-1}	5.1×10^{-1}	5.1×10^{-1}
Inhalation	1.5×10^6	3.0×10^2	1.2×10^7	2.2×10^7
Ingestion	3.7×10^1	2.1×10^2	1.3×10^{-1}	6.3×10^2
External	2.2×10^{-2}	2.2×10^{-2}	2.2×10^{-2}	2.2×10^{-2}
Total	1.5×10^6	5.1×10^2	1.2×10^7	2.2×10^7
		+100,000 yr		
Air submersion	6.0×10^{-2}	6.0×10^{-2}	6.0×10^{-2}	6.0×10^{-2}
Inhalation	3.4×10^4	3.0×10^2	2.0×10^5	6.6×10^5
Ingestion	1.5×10^1	3.1×10^2	1.2×10^{-3}	3.9×10^1
External	6.6×10^{-4}	6.6×10^{-4}	6.6×10^{-4}	6.6×10^{-4}
Total	3.4×10^4	5.1×10^2	2.0×10^5	6.6×10^5
		+1,000,000 yr		
Air submersion	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}
Inhalation	5.5×10^4	2.8×10^2	3.2×10^5	1.1×10^6
Ingestion	1.8	2.2×10^2	3.8×10^{-3}	3.2×10^1
External	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Total	5.5×10^4	4.8×10^2	3.2×10^5	1.1×10^6

TABLE 9.3-25. 70-Year Dose Commitment to the Regional Population from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000-MTHM Equivalent, for Various Times After Closure - U and Pu Recycle, man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}	2.4×10^{3}
Inhalation	4.8×10^{7}	7.9×10^{2}	4.2×10^{8}	6.0×10^{8}
Ingestion	2.1×10^{5}	2.3×10^{2}	3.9×10^{3}	7.9×10^{6}
External	4.1×10^{1}	4.1×10^{1}	4.1×10^{1}	4.1×10^{1}
Total	4.8×10^{7}	3.4×10^{3}	4.2×10^{8}	6.1×10^{8}
		+1000 yr		
Air submersion	1.5	1.5	1.5	1.5
Inhalation	4.8×10^{6}	3.1×10^{2}	3.5×10^{6}	6.6×10^{7}
Ingestion	1.1×10^{2}	2.3×10^{2}	1.2×10^{-1}	1.8×10^{3}
External	9.2×10^{-2}	9.2×10^{-2}	9.2×10^{-2}	9.2×10^{-2}
Total	4.8×10^{6}	5.4×10^{2}	3.5×10^{6}	6.6×10^{7}
		+100,000 yr		
Air submersion	6.6×10^{-2}	6.6×10^{-2}	6.6×10^{-2}	6.6×10^{-2}
Inhalation	6.0×10^{4}	3.2×10^{2}	3.6×10^{5}	1.2×10^{6}
Ingestion	3.6×10^{1}	2.3×10^{2}	1.2×10^{-3}	7.9×10^{1}
External	9.2×10^{-4}	9.2×10^{-4}	9.2×10^{-4}	9.2×10^{-4}
Total	6.0×10^{4}	5.5×10^{2}	3.6×10^{5}	1.2×10^{6}
		+1,000,000 yr		
Air submersion	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}
Inhalation	6.5×10^{4}	3.0×10^{2}	3.6×10^{5}	1.3×10^{6}
Ingestion	2.0	2.2×10^{2}	4.6×10^{-3}	3.7×10^{1}
External	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}
Total	6.5×10^{4}	5.4×10^{2}	3.6×10^{5}	1.3×10^{6}

The regional population was assumed to be replaced by a second-generation population at the end of the 70-year dose commitment period; the doses to that population were calculated. Similarly, doses to a third population, whose 70-year dose commitment period would begin 140 years after the repository breach, were calculated. Doses to the second and third generation are presented in Table 9.3-26.

Doses to the population of the eastern half of the United States were also calculated. It was assumed that the prevailing winds in the upper atmosphere would move the radionuclides released during the accident in an eastward direction, which would expose about 160 million persons east of the reference site. The 2 million persons in the reference population are excluded. Additional assumptions used in these calculations follow:

- All of the respirable material suspended from the meteorite impact would reach the exposed population.
- The exposed population is that in the eastern United States where 80% of the U.S. population resides (taken to be 160 million).
- Depletion by deposition was ignored when calculating average air concentrations at ground level.
- The atmospheric dispersion factor for this population is 8×10^{-3} man-sec/m^3, as determined from References 4 and 5 based on estimates of ^{85}Kr first-pass dispersion.
- The inhalation dose is based on the chronic breathing rate.
- Dose from ingestion is based on a ground concentration of 2.7×10^{-13} Ci/m^2 per Ci released, which is based on an area of 3.8×10^6 km for the eastern United States.[4]
- All of the material is deposited uniformly.

TABLE 9.3-26. Second- and Third-Generation Doses to the Regional Population from a Meteorite Strike of a Repository Containing Wastes from the Reprocessing of 50,000 MTHM Equivalent, 50 yr After Closure, Man-rem

Recycle Mode	Total Body	Thyroid	Lung	Bone
	Second Generation			
U Recycle, Pu in SHLW	1.1×10^3	5.7×10^1	5.7×10^1	4.4×10^3
U Recycle, Pu Storage as PuO_2	1.1×10^3	5.6×10^1	5.6×10^1	4.4×10^3
U and Pu Recycle	9.2×10^2	5.7×10^1	5.7×10^1	3.8×10^3
	Third Generation			
U Recycle, Pu in SHLW	2.2×10^2	1.3×10^1	1.3×10^1	7.9×10^2
U Recycle, Pu Storage as PuO_2	2.2×10^2	1.1×10^1	1.1×10^1	7.9×10^2
U and Pu Recycle	1.9×10^2	1.3×10^1	1.3×10^2	7.3×10^2

Based on these assumptions, dose factors were calculated to relate the maximum individual dose to the U.S. population dose. Dose factors obtained were 1.3×10^5 (U.S. man-rem/rem to the maximum individual) for dose received from direct exposure and ingestion and 8.8×10^4 (U.S. man-rem/rem to the maximum individual) for dose received from inhalation. The 70-year dose commitments to the population of the eastern United States outside of the reference environment are presented in Tables 9.3-27 through 9.3-29.

The largest number of health effects from a repository breach by meteorite impact are calculated to occur just after repository closure. One hundred to eight hundred health effects per million man-rem among the regional population, and the doses from Table 9.3-23, the breach of a repository by meteorite leads to 9200 to 74,000 such effects for uranium recycle with plutonium in SHLW. The number of health effects calcuated for breaches of the repository at 1000, 100,000, and 1,000,000 years after closure are 1700 to 14,000, 30 to 240, and 11 to 88, respectively.

TABLE 9.3-27. 70-Year Dose Commitment to the Population of the Eastern United States from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000 MTHM for Various Times After Closure, U Recycle - Pu Stored in SHLW, Man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.5×10^3	1.5×10^3	1.5×10^3	1.5×10^3
Inhalation	5.5×10^7	4.1×10^2	3.4×10^8	9.2×10^8
Ingestion	1.3×10^7	1.5×10^4	5.6×10^4	5.3×10^7
External	3.8×10^5	3.8×10^5	3.8×10^5	3.8×10^5
Total	6.8×10^7	4.0×10^5	3.4×10^8	9.7×10^8
		+ 1,000 yr		
Air submersion	1.3	1.3	1.3	1.3
Inhalation	1.1×10^7	1.8×10^2	7.3×10^7	1.8×10^8
Ingestion	4.0×10^3	1.5×10^4	1.7	8.6×10^4
External	3.3×10^3	3.3×10^3	3.3×10^3	3.3×10^3
Total	1.1×10^7	1.8×10^4	7.3×10^7	1.8×10^8
		+ 100,000 yr		
Air submersion	4.8×10^{-2}	4.8×10^{-2}	4.8×10^{-2}	4.8×10^{-2}
Inhalation	1.8×10^5	1.8×10^2	1.2×10^6	3.7×10^6
Ingestion	1.1×10^4	1.5×10^4	5.1×10^{-1}	1.9×10^4
External	5.0×10^2	5.0×10^2	5.0×10^2	5.0×10^2
Total	1.9×10^5	1.5×10^4	1.2×10^6	3.7×10^6
		+ 1,000,000 yr		
Air submersion	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}
Inhalation	6.6×10^4	1.7×10^2	4.0×10^5	1.3×10^6
Ingestion	2.1×10^3	1.4×10^4	2.6×10^{-2}	4.5×10^3
External	2.6×10^2	2.6×10^2	2.6×10^2	2.6×10^2
Total	6.8×10^4	1.4×10^4	4.0×10^5	1.3×10^6

TABLE 9.3-28. 70-Year Dose Commitment to the Population of the Eastern United States from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000 MTHM for Various Times After Closure, U Recycle - Pu Stored as PuO_2, Man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air Submersion	1.5×10^3	1.5×10^3	1.5×10^3	1.5×10^3
Inhalation	1.2×10^7	4.2×10^2	5.5×10^7	9.9×10^7
Ingestion	1.3×10^7	1.5×10^4	5.6×10^4	5.3×10^7
External	3.8×10^5	3.8×10^5	3.8×10^5	3.8×10^5
Total	2.5×10^7	4.0×10^5	5.5×10^7	1.5×10^8
		+ 1,000 yr		
Air submersion	3.2×10^{-1}	3.2×10^{-1}	3.2×10^{-1}	3.2×10^{-1}
Inhalation	9.2×10^5	1.8×10^2	7.3×10^6	1.4×10^7
Ingestion	4.0×10^3	1.5×10^4	1.7	8.6×10^4
External	3.3×10^3	3.3×10^3	3.3×10^3	3.3×10^3
Total	9.3×10^5	1.8×10^4	7.3×10^6	1.4×10^7
		+ 100,00 yr		
Air submersion	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}
Inhalation	2.1×10^4	1.8×10^2	1.3×10^5	4.2×10^5
Ingestion	2.7×10^2	1.5×10^4	5.1×10^{-1}	7.3×10^2
External	1.8×10^2	1.8×10^2	1.8×10^2	1.8×10^2
Total	2.1×10^4	1.5×10^4	1.3×10^5	4.2×10^5
		+ 1,000,000 yr		
Air Submersion	7.3×10^{-3}	7.3×10^{-3}	7.3×10^{-3}	7.3×10^{-3}
Inhalation	3.4×10^4	1.7×10^2	2.0×10^5	6.6×10^5
Ingestion	5.0×10^1	1.4×10^4	9.9×10^{-2}	6.6×10^2
External	1.5×10^2	1.5×10^2	1.5×10^2	1.5×10^2
Total	3.4×10^4	1.4×10^4	2.0×10^5	6.6×10^5

TABLE 9.3-29. 70-Year Dose Commitment to the Population of the Eastern United States from Breach by Meteorite of a Repository Containing Wastes from Reprocessing 50,000 MTHM for Various Times After Closure, U and Pu Recycle, man-rem

Pathway	Total Body	Thyroid	Lung	Bone
		At Closure		
Air submersion	1.7×10^3	1.7×10^3	1.7×10^3	1.7×10^3
Inhalation	2.9×10^7	4.8×10^2	2.6×10^8	3.7×10^8
Ingestion	1.1×10^7	1.5×10^4	5.7×10^4	4.7×10^7
External	3.9×10^5	3.9×10^5	3.9×10^5	3.9×10^5
Total	4.0×10^7	4.1×10^5	2.6×10^8	4.2×10^8
		+ 1,000 Yr		
Air submersion	9.2×10^{-1}	9.2×10^{-1}	9.2×10^{-1}	9.2×10^{-1}
Inhalation	2.9×10^6	2.0×10^4	2.1×10^7	4.1×10^7
Ingestion	1.5×10^3	1.5×10^4	2.4	2.6×10^4
External	4.0×10^3	4.0×10^3	4.0×10^3	4.0×10^3
Total	2.9×10^6	3.8×10^4	2.1×10^7	4.1×10^7
		+ 100,000 Yr		
Air submersion	4.1×10^{-2}	4.1×10^{-2}	4.1×10^{-2}	4.1×10^{-2}
Inhalation	3.7×10^4	2.0×10^4	2.2×10^5	7.3×10^5
Ingestion	6.2×10^2	1.5×10^4	5.1×10^1	1.4×10^3
External	2.2×10^2	2.2×10^2	2.2×10^2	2.2×10^2
Total	3.8×10^4	3.5×10^4	2.2×10^5	7.3×10^5
		+ 1,000,000 Yr		
Air submersion	8.6×10^{-3}	8.6×10^{-3}	8.6×10^{-3}	8.6×10^{-3}
Inhalation	4.0×10^4	1.8×10^2	2.2×10^5	7.9×10^5
Ingestion	5.6×10^1	1.5×10^4	1.1×10^{-1}	7.9×10^2
External	1.8×10^2	1.8×10^2	1.8×10^2	1.8×10^2
Total	4.0×10^4	1.5×10^4	2.2×10^5	7.9×10^5

Over the same 70-year period about 1,700,000 people of the 2,000,000 reference population will have died regardless of the presence, absence, or breach of the reference repository.

In this discussion essentially equal importance has been given to societal costs of an excess cancer death as to costs of a serious genetic effect. At the present level of knowledge, the relative importance of these effects, if indeed they do occur, is not known. However, a given number of serious genetic effects may be more costly to society as we know it today than would an equal number of excess cancer deaths.

The preceding presentation has assumed that the meteorite strike did occur. That is, the incident had a probability of one over the period of interest. the probability of a meteorite striking the surface over the repository and producing a crater 2 km in diameter has been

estimated to be 2×10^{-7} over a 1-million-yr period or 2×10^{-13}/yr. If risk is taken as probability times consequences, the societal risk of death or serious genetic defect would be less than 2×10^{-3} over 1 million years from the largest dose (70-yr dose from U recycle, Pu in HLW) to the population. For perspective, in the United States the societal risk of death by lightning is about 120/yr, or about 1×10^{8}/million yr.[6] Thus, in this framework, the societal risk from a meteorite breach of a repository is about 2×10^{-11} times that from lightning strikes.

Based on the 1% release rate of ^{3}H, ^{14}C, and ^{85}Kr, the 70-year total body dose commitment to the worldwide population would amount to 1.1×10^{4} man-rem for a breach at 50 years, 9.8×10^{2} man-rem for a breach at 1,000 years, and 2×10^{-2} man-rem for a breach at 100,000 years after closure.

The meteorite postulated in this repository breach was assumed to be sufficiently large to penetrate to a depth of 600 m. Meteorites may produce rock fractures to depths on the order of 4 times the crater depth.[7] Thus, a smaller meteorite, while not causing a direct release of radioactive material, could open the repository to entry of water. For example, a meteorite might produce a crater about 150 m deep and fracture to the 600-m depth. Such an occurrence would be expected to have a somewhat higher probability than that of the 600-m-deep crater produced by a meteorite. The radiological consequences of a meteorite producing a fracture breach are believed to be no worse than a faulting and flooding event, which is described in detail in a later section.

9.3.5 Repository Breach by Drilling (Accident 7.12)

In this accident it is assumed that at about 1000 years after repository closure someone drills 600 m into a waste repository in search of a mineral resource or for geologic study. Repository markers are presumably no longer evident, are misunderstood, or are ignored. It is assumed that these individuals, while having the technology to drill to that depth, do not possess or do not apply the knowledge and apparatus to assay material brought up in the drilling process and to discover its radioactive properties. The calculation of consequences in terms of dose proceeds on that basis.

That the drill crew may not be aware of radioactive material in the drilling mud as it is brought up may be reasonable enough. However, once samples are sent to their assay laboratory it is doubtful that the drillers would remain ignorant for long of the radioactive nature of their exploratory effort. The radiation characteristics of material brought up, after passing through a solidified high-level waste canister, would not resemble natural ores.

Because it was not possible to determine a probability for exploratory drilling, it was not possible to assign an overall probability to this event. However, it may be likely that someone would explore for salt, potash, oil, etc., in the area of a salt repository because of the same exploration principles that established the presence of the formation in the first place. In other formations, such as granite, shale and basalt, there does not seem to be as strong an association with particular resources as in the case of salt. The probability of drilling through a waste canister from some point on the surface above the repository was determined to be 0.005 (see Table 7.3.28, DOE/ET-0028.[1]). The probability of the drilling

event cannot exceed 0.005*, but since the overall probability is highly uncertain the accident and its consequences are presented on a "what if" basis.

It is assumed that one-fourth of a canister (a reference SHLW canister containing 3 MTHM equivalent) is circulated to the surface with the drilling mud and that the radioactive material is uniformly distributed over 0.5 ha in the top 5 cm of the surface soil.

Table 9.3-30 lists the expected releases to the air from contaminated surface soil (radioactive material concentrated in the top 1 cm of the soil) assuming 1) a resuspension factor of 0.011/yr and 2) one-fourth of the radioactive material in the top 5 cm is available for resuspension. Based on the releases given in Table 9.3.30 and methods of dose calculations presented in Appendix B, first-year doses and 70-year dose commitments to the maximum individual (who will reside and grow crops for his consumption on the contaminted land) were calculated and are presented in Table 9.3-31. It is also assumed that the maximum individual is exposed, on the average, to the contaminated soil for 12 hr/day.

TABLE 9.3-30. Radionuclides Released to the Atmosphere from Salt Repository Breach by Drilling Accident-Spent Fuel Case, Ci

Radionuclide	U & Pu Recycle	U Recycle Only, Pu in Waste	U Recycle Only, PuO_2 Stored
^{14}C	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}
^{126}Sb	8.7×10^{-5}	7.2×10^{-5}	7.2×10^{-5}
^{126}Sn	8.7×10^{-5}	7.2×10^{-5}	7.2×10^{-5}
^{129}I	5.6×10^{-6}	5.2×10^{-6}	5.2×10^{-6}
^{239}Np	1.0×10^{-2}	1.8×10^{-3}	1.8×10^{-3}
^{240}Pu	5.5×10^{-3}	6.4×10^{-2}	1.0×10^{-3}
^{241}Am	5.6×10^{-2}	1.4×10^{-1}	2.2×10^{-2}
^{239}Pu	9.5×10^{-4}	4.6×10^{-2}	4.7×10^{-4}

The predominant mode of exposure is direct radiation from contaminated soil. As a consequence, dose to the various organs is substantially the same the first year. During the 70-yr dose period the dose from ingestion pathway increases substantially, particularly in terms of dose to bone. The first-year doses are probably not large enough for serious acute effects, at least in the case of the U recycle with PuO_2 stored elsewhere. In the case of U & Pu recycle and U recycle only with Pu in HLW, an annual total body dose (over 70 years) of about 150 rem would result. Although no comparable human experience exists, it would be expected that such a dose would have severe adverse effects on the individual exposed (signficant life shortening, increased likelihood of contracting leukemia, etc.)

If it were postulated that the 0.5 ha of contaminated land was occupied by a housing project soon after the drilling incident (an unlikely event since assay of the drill core should suggest the presence of subsurface resources) with about 0.1 ha per lot, five families (probably about 25 individuals) might be exposed as was the maximum individual.

* If drilling occurs, the probability of penetrating the waste is 0.005 based on geometrical considerations.

TABLE 9.3-31. Doses to Maximum Individual[a] from a Repository Breach by Exploratory Drilling - Year 3050, rem

Reprocessing Mode	Total Body	Thyroid[b]	Lung	Bone
		First-Year Dose		
HLW Canister				
U & Pu recycle	1.5×10^2	1.5×10^2	1.7×10^2	1.5×10^2
U recycle only, Pu in HLW	1.4×10^2	1.4×10^2	1.8×10^2	1.4×10^2
U recycle only, PuO_2 stored	5.6×10^1	4.3×10^1	5.6×10^1	4.4×10^1
		70-Year Accumulated Dose		
HLW Canister				
U & Pu recycle	1.1×10^4	1.1×10^4	1.1×10^4	1.1×10^4
U Recycle only, Pu in HLW	9.9×10^3	9.7×10^3	9.6×10^3	1.6×10^4
U recycle only, PuO_2 stored	3.4×10^3	3.2×10^3	3.0×10^3	3.7×10^3

a. The maximum individual is defined as a permanent resident on the 0.5 ha of contaminated land where the time-integrated atmospheric dispersion factor (E/Q) is 3.2×10^{-2} sec/m^3. Assumes the radioactive material is uniformly distributed in the top 15 cm of soil.
b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

Seventy-year accumulated doses were also calculated for the regional population and are presented in Table 9.3-32. All of the doses to the regional population (whose exposure would result principally from resuspension and air transport of radionuclides) are substantially less than those that would be received from naturally occurring radioactive sources (1.4×10^7 man-rem over the same period).

TABLE 9.3-32. 70-Year Doses to the Regional Population[a] from Breach of Repository by Exploratory Drilling - Year 3050, man-rem

Reprocessing Mode	Total Body	Thyroid	Lung	Bone
HLW Waste Canister				
U & Pu recycle	7.3×10^2	9.7×10^{-2}	5.6×10^3	1.0×10^4
U recycle only, Pu in HLW	4.3×10^3	8.3×10^{-2}	9.0×10^3	2.1×10^4
U recycle only, PuO_2 stored	4.3×10^2	4.4×10^{-2}	3.3×10^3	6.1×10^3

a. None of the regional population resides on the 0.5 ha of contaminated land.

In the case of a repository in salt, the land (0.5 ha) would likely be contaminated with salt brought up with the drilling mud. As developed in more detail in Section 4 of this report, the ground contaminated by the resulting concentration of salt would not be well tolerated by ordinary crops.

Breach of a repository by exploratory drilling would not constitue a signficant societal risk regardless of recycle option and geologic medium chosen for disposal of wastes. However, such a breach would be a very serious hazard with a probability of substantially less than 0.005 to about 20 people in the immediate area in the case of U & Pu recycle and U-only recycle with plutonium in the waste.

If it is known that a drill has passed through a waste canister and brought waste to the surface, it should be a fairly simple process by standard decontamination methods to recover the contaminants, send them to another repository, and preclude essentially all of the radiological consequences.

9.3.6 Breach of Repository by Fault Fracture and Flooding (Accident 7.15)

This scenario is a combination of improbable events. First, a fracture or series of fractures either from the surface or from near an aquifer is assumed to penetrate the repository. The fractures are also assumed to connect and to permit water to reach the wastes. Two cases are presented: in the first case a fairly large stream of water penetrates the repository and leaches out radioactive waste and then, following a hypothetical conduit, returns to the surface to form a stream; the second case presumes water reaches the repository and leaches out radioactive waste, some of which is held up by adsorption on soils outside the repository area before slowly working its way to the biosphere.

It should be noted that these accident scenarios assume an improbable combination of events with very low probabilities of occurrence, and in some cases these assumptions are contrary to the evidence available. For example, it is generally accepted that faulting of thick salt units does not lead to formation of permeable zones and that the plastic behavior of salt tends to heal any opening. Most of the known faults in salt formations confirm this self-healing behavior of halite (salt).[2] Also, massive salt units generally occur in a geologic environment that contains clays, shales and argillaceous units that again tend to deform plastically. Faults in rock material that yields by brittle fracture (granite, basalt, some carbonates) are more likely to form permeable zones of crushed, broken rock than faults in salt. However, even in brittle rocks a fault zone may, through the grinding and crushing of the material, form a continuously permeable conduit to the repository, even if a fault should occur through the repository to the land surface.

A "worst" situation is also assumed with respect to the waste form. In particular, leach rates with water in contact with solidifed reprocessing wastes are assumed to be for devitrified glass in a fractured state.

The purpose of putting wastes into glass is to immobilize all of the fission product oxides and place them in a form that has reduced corrosion rates. These reduced rates are believed to be adequate for storage. As a matter of fact, about 10% of the waste components of the waste glass are in a crystalline rather than a vitrified state. These represent very stable phases

that have low corrosion rates. Thus when reference is made to the waste glass devitrifying, it is implied that there are additional crystalline forms in the vitrified matrix. The overall corrosion rate of the "devitrified waste" is sometimes higher by a factor of about 10 over the vitrified state; this higher value is the leach rate used in this study but further corrected on the assumption that the glass is in a fractured state brought about by cooling stresses. As would be expected, the measured leach rate is not the same for all components of the glass. In this repository breach scenario it was assumed that all nuclides leach at the maximum rate, whereas data from long-term studies of radioactive waste glasses indicate that uranium and transuranic elements leach at 10% to 1% of the leach rate of elements having the maximum leach rate.

In the first scenario the repository is breached by fracturing in the year 2050 (just after filling, sealing, and decommissioning of surface facilities) or 1000, 100,000 or 1,000,000 years thereafter. Water in the form of a stream of 2.8 m^3/sec (100 cfs), invades the repository, flows past the wastes and enters the reference environment in the R River about 10 km from the repository center. The stream is assumed to be in contact with the wastes for one year. (This case simulates the subsequent sealing of the breach line by further earth movement, healing because of the nature of the host rock or because of plugging of the water path by silt carried by the stream.)

For an estimate of potential leach rate of waste by the stream, several studies were considered. Two important factors affecting leach rate of a waste material are the waste form (chemical nature) and the temperature of the solid-liquid interaction zone. Data reported in PNL-2625,[8] under repository conditions more severe than would occur during the 2050 breach, indicate leach rates ranging from 10^{-8} to 10^{-5} g/cm^2-day for reactions between aqueous solutions and waste glasses in a devitrified and fractured state. Other studies by McCarthy et al.[9] at 300°C and 300 atm have suggested changes in properties that might lead to higher leach rates for some radionuclides in borosilicate glass. However, with recombination of some of the radionuclides with the immediate environment, a more stable form with a lower leach rate could result. Other studies in field situations at lower temperatures, lower pressures, and ground saturated with water have shown rates as low or lower than 10^{-10} gm/cm^2-day for radionuclides in nepheline syenite glass.[10] As a result of the above studies, leach rates utilized in consequence analyses (Table 9.3-33) are considered reasonably conservative in view of the likely water temperature. In addition, for leaching beginning in 2050, when temperatures from decay heat are still significant, the waste container is not taken into consideration (thus leach rates may be higher but amounts leached may be lower because of the presence of the canister). It is estimated that entering water would decrease the temperature of the glass canister below 200°C for repository breach in the year 2050 and below 100°C for breaches at future times.[11] It is also assumed that all of the waste glass would devitrify, although in all probability only a central portion would devitrify.

For dose calculations related to vitrified high-level waste (the major contributor to dose from reprocessing wastes), leach rates enter the dose calculations so that doses assuming different leach rates may be obtained by multiplying the tabulated dose by the ratio of the assumed

leach rate to the listed leach rate. (A later analysis for groundwater transport obviates this problem in part by bounding the leaching of all wastes between 1 yr and 1000 yr.)

TABLE 9.3-33. Estimated Leach Rate for Various Forms of Reprocessing Radioactive Wastes

Radioactive Waste Form	Leach Rate, gm/cm^2-day	Number of Canisters Contacted
High-level waste glass (assumed to be devitrified and fractured, and without any protection from the canister; 1-cm cubes)	1×10^{-4} for first 10 days	210
	1×10^{-5} thereafter	
Intermediate-level and low-level wastes	1×10^{-4}	480, 560
Fuel residue (hulls and hardware)	1×10^{-5}	30

Radionuclides released to the R River for this event, occurring in the year 2050 or 1000, 100,000 or 1,000,000 years thereafter, are given for the three fuel reprocessing options in Tables 9.3-34 through 9.3-36.

The first-year and 70-year total-body dose commitments were calculated for the maximum individual using the data in Tables 9.3-34 to 9.3-36, the methods described in Appendix B and the following assumptions. For wastes in other than a salt repository it was assumed that aquatic food was taken from, and recreational activities occurred near, the 2.8 m^3/sec stream of water from the repository. Drinking water was assumed to be taken from the R River downstream from the point of contamination entry. Contaminants in farm products and ground contamination doses were determined based on irrigation of land with water from the R River. In the case of a repository in salt it was concluded that the 2.8 m^3/sec effluent stream would be so laden with salt that no fresh-water biota would be present and that the maximum individual would derive his aquatic food from the R River and conduct his recreational activities near that river. Population doses were also calculated on the basis of contamination of water in the R River. Because the 70-year dose commitment to the maximum individual was so large for breach of repository in 2050 (Table 9.3-37), particularly for repositories in other than salt, a first-year dose was also calculated and is presented in Table 9.3-38. Total-body doses to the maximum individual in the first year for a repository in salt are 50 rem and are independent of reprocessing option. The total-body doses to the maximum individual from breaches of a nonsalt repository are 1700 rem in the first year and are independent of reprocessing option.

The doses associated with the breach of a salt repository are 10 times the permissible annual dose for occupational exposures. Since planned whole-body exposures up to 25 rem are reasonably accepted for emergency conditions, it follows that accidental doses up to the same magnitude should not cause major concern.[12] A total-body dose of 1700 rem to the maximum individual in the nonsalt repository cases is presumed to be fatal. It is not likely that a

breach of repository in the year 2050 would go unnoticed, and measures would be taken to monitor all water supplies that might have even a remote possibility of being contaminated. Thus, the calcuated doses and consequences seem most unlikely to occur in practice.

TABLE 9.3-34. Radionuclides Released from Breach of Repository for U - Pu Recycle Waste, Faulting and Flooding, Ci

Nuclide	Year 2050	+ 1,000 yr	+ 100,000 yr	+ 1,000,000 yr
^{3}H	2.3×10^{3}			
^{14}C	6.6	5.9	3.8×10^{-5}	
^{54}Mn	4.2×10^{-2}			
^{55}Fe	7.1×10^{2}			
^{60}Co	6.4×10^{3}			
^{59}Ni	1.7×10^{2}	1.7×10^{2}	7.0×10^{1}	2.9×10^{-2}
^{63}Ni	2.0×10^{4}	1.9×10^{1}		
^{79}Se	1.4	1.4	4.9×10^{-1}	3.3×10^{-5}
^{90}Sr	1.0×10^{5}	1.3×10^{-5}		
^{90}Y	1.0×10^{5}	1.3×10^{-5}		
^{93}Zr	7.0	7.0	6.7	4.4
^{93m}Nb	7.0	7.0	6.7	4.4
^{99}Tc	5.5×10^{1}	5.4×10^{1}	3.9×10^{1}	2.0
^{106}Rh	1.4×10^{1}			
^{106}Ru	1.4×10^{1}			
^{107}Pb	5.3×10^{-1}	5.3×10^{-1}	5.2×10^{-1}	4.8×10^{-1}
^{123}Sn	8.5×10^{-8}			
^{125}Sb	1.3×10^{2}			
^{125m}Te	3.0×10^{1}			
^{126}Sn	2.4	2.4	1.2	2.3×10^{-3}
^{126m}Sb	2.4	2.4	1.2	2.3×10^{-3}
^{126}Sb	2.4	2.4	1.2	2.3×10^{-3}
^{127m}Te	6.7×10^{-9}			
^{127}Te	6.7×10^{-9}			
^{129}I	8.5	8.5	8.5	8.1
^{134}Cs	4.6×10^{2}			
^{135}Cs	1.5	1.5	1.4	1.2
^{137}Cs	1.6×10^{6}	8.8×10^{-5}		
^{137m}Ba	1.6×10^{6}	8.6×10^{-5}		
^{144}Ce	2.7			
^{144}Pr	2.7			
^{147}Pm	9.3×10^{2}			
^{151}Sm	3.9×10^{3}	2.5		
^{154}Eu	6.1×10^{3}			
^{155}Eu	1.0×10^{1}			

TABLE 9.3-34. (contd)

Nuclide	Year 2050	+ 1,000 yr	+ 100,000 yr	+ 1,000,000 yr
^{210}Pb	1.9×10^{-6}	4.5×10^{-4}	1.8×10^{-1}	4.2×10^{-2}
^{210}Bi	1.9×10^{-6}	4.5×10^{-4}	1.8×10^{-1}	4.2×10^{-2}
^{224}Ra	4.9×10^{-1}	4.8×10^{-4}	1.1×10^{-7}	1.1×10^{-6}
^{226}Ra	4.1×10^{-6}	4.4×10^{-4}	1.8×10^{-1}	4.2×10^{-2}
^{227}Ac	8.6×10^{-5}	1.5×10^{-4}	3.1×10^{-3}	4.5×10^{-3}
^{228}Th	4.9×10^{-1}	4.8×10^{-4}	1.1×10^{-7}	1.1×10^{-6}
^{229}Th	7.8×10^{-7}	6.0×10^{-4}	1.3	3.3
^{230}Th	2.7×10^{-4}	2.5×10^{-3}	1.8×10^{-1}	4.2×10^{-2}
^{232}Th	2.2×10^{-11}	5.5×10^{-10}	1.1×10^{-7}	1.1×10^{-6}
^{233}Pa	2.4	3.4	3.6	2.7
^{232}U	4.1×10^{-1}	4.6×10^{-4}		
^{233}U	3.6×10^{-4}	1.2×10^{-2}	1.3	2.9
^{234}U	7.5×10^{-2}	3.5×10^{-1}	2.7×10^{-1}	3.2×10^{-2}
^{236}U	1.1×10^{-2}	1.5×10^{-2}	5.7×10^{-2}	5.6×10^{-2}
^{238}U	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
^{237}Np	2.4	3.4	3.6	2.7
^{239}Np	3.1×10^{2}	2.8×10^{2}	3.8×10^{-2}	
^{238}Pu	3.4×10^{2}	1.3×10^{1}		
^{239}Pu	1.9×10^{1}	2.6×10^{1}	9.2	9.5×10^{-9}
^{240}Pu	1.2×10^{2}	1.5×10^{2}	6.6×10^{-3}	
^{241}Pu	2.3×10^{3}	1.3×10^{1}	3.4×10^{-3}	
^{242}Pu	2.5×10^{-1}	2.8×10^{-1}	2.3×10^{-1}	4.4×10^{-2}
^{241}Am	6.3×10^{3}	1.5×10^{3}	3.4×10^{-3}	
^{242m}Am	3.1×10^{2}	6.7		
^{242}Am	3.1×10^{2}	6.7		
^{243}Am	3.1×10^{2}	2.8×10^{2}	3.8×10^{-2}	
^{242}Cm	2.6×10^{2}	5.5		
^{244}Cm	1.6×10^{4}	2.0×10^{-5}		
^{245}Cm	1.4×10^{1}	1.3×10^{1}	3.4×10^{-3}	

TABLE 9.3-35. Radionuclides Released from Breach of Repository Containing U Recycle Waste with Pu Stored in High-Level Waste, -Faulting and Flooding, Ci

Nuclide	Year 2050	+ 1,000 yr	+ 100,000 yr	+ 1,000,000 yr
^{3}H	2.1×10^{3}			
^{14}C	6.9	6.1	3.9×10^{-5}	
^{54}Mn	3.8×10^{-2}			
^{55}Fe	8.4×10^{2}			
^{60}Co	6.7×10^{3}			
^{59}Ni	1.9×10^{2}	1.9×10^{2}	8.0×10^{1}	3.3×10^{-2}
^{63}Ni	2.3×10^{4}	2.2×10^{1}		
^{79}Se	1.5	1.5	5.1×10^{-1}	3.5×10^{-5}
^{90}Sr	1.1×10^{5}	1.5×10^{-5}		
^{90}Y	1.1×10^{5}	1.5×10^{-5}		
^{93}Zr	7.5	7.5	7.1	4.7
^{93m}Nb	7.5	7.5	7.1	4.7
^{99}Tc	5.4×10^{1}	5.4×10^{1}	3.9×10^{1}	2.0
^{106}Rh	1.1×10^{1}			
^{106}Ru	1.1×10^{1}			
^{107}Pd	4.1×10^{-1}	4.1×10^{-1}	4.0×10^{-1}	3.7×10^{-1}
^{123}Sn	7.9×10^{-8}			
^{125}Sb	1.0×10^{2}			
^{125m}Te	2.4×10^{1}			
^{126}Sn	2.0	2.0	9.9×10^{-1}	1.9×10^{-3}
^{126m}Sb	2.0	2.0	9.9×10^{-1}	1.9×10^{-3}
^{126}Sb	2.0	2.0	9.9×10^{-1}	1.9×10^{-3}
^{127m}Te	6.3×10^{-9}			
^{127}Te	6.3×10^{-9}			
^{129}I	7.9	7.9	7.9	7.6
^{134}Cs	4.5×10^{2}			
^{135}Cs	1.2	1.2	1.1	9.2×10^{-1}
^{137}Cs	1.6×10^{5}	8.8×10^{-5}		
^{137m}Ba	1.6×10^{5}	8.5×10^{-5}		
^{144}Ce	2.8			
^{144}Pr	2.8			
^{147}Pm	9.5×10^{2}			

TABLE 9.3-35. (contd)

Nuclide	Year 2050	+ 1,000 yr	+ 100,000 yr	+ 1,000,000 yr
^{151}Sm	3.6×10^{3}	2.3		
^{154}Eu	5.1×10^{3}			
^{155}Eu	8.0			
^{210}Pb	2.7×10^{-6}	8.2×10^{-3}	3.4	6.2×10^{-1}
^{210}Bi	2.7×10^{-6}	8.2×10^{-3}	3.4	6.2×10^{-1}
^{224}Ra	5.1×10^{-2}	5.5×10^{-5}	2.5×10^{-6}	2.7×10^{-5}
^{226}Ra	6.6×10^{-6}	8.1×10^{-3}	3.3	6.0×10^{-1}
^{227}Ac	1.1×10^{-4}	2.0×10^{-4}	3.2×10^{-2}	4.5×10^{-2}
^{228}Th	5.1×10^{-2}	5.5×10^{-5}	2.5×10^{-6}	2.7×10^{-5}
^{229}Th	8.1×10^{-7}	8.4×10^{-4}	2.2	5.5
^{230}Th	5.8×10^{-4}	4.9×10^{-2}	3.3	6.1×10^{-1}
^{232}Th	2.9×10^{-11}	1.9×10^{-9}	2.5×10^{-6}	2.7×10^{-5}
^{233}Pa	2.8	5.3	5.9	4.4
^{232}U	5.0×10^{-2}	5.3×10^{-5}		
^{233}U	3.9×10^{-4}	1.8×10^{-2}	2.1	4.7
^{234}U	1.5	6.7	5.1	4.2×10^{-1}
^{236}U	1.6×10^{-2}	6.4×10^{-2}	5.5×10^{-1}	5.4×10^{-1}
^{238}U	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
^{237}Np	2.8	5.3	5.9	4.4
^{239}Np	5.5×10^{1}	5.0×10^{1}	6.8×10^{-3}	
^{238}Pu	1.5×10^{5}	4.1×10^{1}		
^{239}Pu	1.3×10^{3}	1.3×10^{3}	7.6×10^{1}	7.0×10^{-8}
^{240}Pu	1.9×10^{3}	1.7×10^{3}	7.6×10^{-2}	
^{241}Pu	8.8×10^{4}	6.4×10^{-1}	1.7×10^{-4}	
^{242}Pu	6.4	6.4	5.4	1.0
^{241}Am	1.3×10^{4}	3.8×10^{3}	1.7×10^{-4}	
^{242m}Am	3.9×10^{1}	8.0×10^{-1}		
^{242}Am	3.9×10^{1}	8.0×10^{-1}		
^{243}Am	5.5×10^{1}	5.0×10^{1}	6.8×10^{-3}	
^{242}Cm	3.2×10^{1}	6.6×10^{-1}		
^{244}Cm	1.2×10^{3}	1.7×10^{-6}		
^{245}Cm	7.0×10^{-1}	6.4×10^{-1}	1.7×10^{-4}	

TABLE 9.3-36. Radionuclides Released from Breach of Repository Containing U-Only Recycle Waste with Pu in PuO_2 Storage - Faulting and Flooding, Ci

Nuclide	Year 2050	+ 1,000 yr	+ 100,000 yr	+ 1,000,000 yr
^{3}H	2.1×10^{3}			
^{14}C	6.9	6.1	3.9×10^{-5}	
^{54}Mn	3.8×10^{-2}			
^{55}Fe	8.4×10^{2}			
^{60}Co	6.7×10^{3}			
^{59}Ni	1.9×10^{2}	1.9×10^{2}	8.0×10^{1}	3.3×10^{-2}
^{63}Ni	2.3×10^{4}	2.2×10^{1}		
^{79}Se	1.5	1.5	5.1×10^{-1}	3.5×10^{-5}
^{90}Sr	1.1×10^{5}	1.5×10^{-5}		
^{90}Y	1.1×10^{5}	1.5×10^{-5}		
^{93}Zr	7.5	7.5	7.1	4.7
^{93m}Nb	7.5	7.5	7.1	4.7
^{99}Tc	5.4×10^{1}	5.4×10^{1}	3.9×10^{1}	2.0
^{106}Rh	1.1×10^{1}			
^{106}Ru	1.1×10^{1}			
^{107}Pd	4.1×10^{-1}	4.1×10^{-1}	4.0×10^{-1}	3.7×10^{-1}
^{123}Sn	7.9×10^{-8}			
^{125}Sb	1.0×10^{2}			
^{125m}Te	1.0×10^{2}			
^{126}Sn	2.0	2.0	9.9×10^{-1}	1.9×10^{-3}
^{126m}Sb	2.0	2.0	9.9×10^{-1}	1.9×10^{-3}
^{126}Sb	2.0	2.0	9.9×10^{-1}	1.9×10^{-3}
^{127m}Te	6.3×10^{-9}			
^{127}Te	6.2×10^{-9}			
^{129}I	7.9	7.9	7.9	7.6
^{134}Cs	4.5×10^{2}			
^{135}Cs	1.2	1.2	1.1	9.2×10^{-1}
^{137}Cs	1.6×10^{5}	8.8×10^{-5}		
^{137m}Ba	1.6×10^{5}	8.5×10^{-5}		
^{144}Ce	2.8			
^{144}Pr	2.8			
^{147}Pm	9.5×10^{2}			

TABLE 9.3-36. (contd)

Nuclide	Year 2050	+ 1,000 yr	+ 100,000 yr	+ 1,000,000 yr
^{151}Sm	3.6×10^{3}	2.3		
^{154}Eu	5.1×10^{3}			
^{155}Eu	8.0			
^{210}Pb	2.3×10^{-6}	2.9×10^{-4}	7.2×10^{-2}	2.3×10^{-2}
^{210}Bi	2.3×10^{-6}	2.9×10^{-4}	7.2×10^{-2}	2.3×10^{-2}
^{224}Ra	1.5×10^{-3}	1.3×10^{-6}	9.1×10^{-8}	9.2×10^{-7}
^{226}Ra	5.0×10^{-6}	2.8×10^{-4}	7.1×10^{-2}	2.2×10^{-2}
^{227}Ac	1.1×10^{-4}	1.9×10^{-4}	1.3×10^{-3}	1.7×10^{-3}
^{228}Th	1.5×10^{-3}	1.3×10^{-6}	9.1×10^{-8}	9.2×10^{-7}
^{229}Th	8.0×10^{-7}	6.2×10^{-4}	1.2	2.9
^{230}Th	3.4×10^{-4}	1.4×10^{-3}	7.1×10^{-2}	2.3×10^{-2}
^{232}Th	2.8×10^{-11}	6.7×10^{-10}	9.1×10^{-8}	9.1×10^{-7}
^{233}Pa	2.7	3.1	3.2	2.4
^{232}U	1.2×10^{-3}	1.2×10^{-6}		
^{233}U	3.8×10^{-4}	1.2×10^{-2}	1.1	2.5
^{234}U	6.8×10^{-2}	1.4×10^{-1}	1.1×10^{-1}	1.9×10^{-2}
^{236}U	1.4×10^{-2}	1.5×10^{-2}	2.2×10^{-2}	2.2×10^{-2}
^{238}U	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
^{237}Np	2.7	3.1	3.2	2.4
^{239}Np	5.5×10^{1}	5.0×10^{1}	6.8×10^{-3}	
^{238}Pu	1.5×10^{2}	1.8		
^{239}Pu	1.2×10^{1}	1.3×10^{1}	2.2	1.9
^{240}Pu	2.6×10^{1}	2.7×10^{1}	1.2×10^{-3}	
^{241}Pu	8.1×10^{2}	6.4×10^{-1}	1.7×10^{-4}	
^{242}Pu	6.0×10^{-2}	6.3×10^{-2}	5.2×10^{-2}	1.0×10^{-2}
^{241}Am	2.5×10^{3}	5.9×10^{2}	1.7×10^{-4}	
^{242m}Am	3.9×10^{1}	8.0×10^{-1}		
^{242}Am	3.9×10^{1}	8.0×10^{-1}		
^{243}Am	5.5×10^{1}	5.0×10^{1}	6.8×10^{-3}	
^{242}Cm	3.2×10^{1}	6.6×10^{-1}		
^{244}Cm	1.2×10^{13}	1.7×10^{-6}		
^{245}Cm	7.0×10^{-1}	6.4×10^{-1}	1.7×10^{-4}	

TABLE 9.3-37. 70-Year Dose Commitment to the Maximum Individual Repository Breach by Faulting and Flooding, rem

Recycle Mode	Salt Repository Total Body	Thyroid	Lung	Bone	Nonsalt Repository Total Body	Thyroid	Lung	Bone
					Year 2050			
U & Pu Recycle	6.1×10^{2}	3.0×10^{1}	4.9×10^{1}	2.1×10^{3}	7.4×10^{3}	8.4×10^{2}	1.3×10^{3}	1.9×10^{4}
U/Pu in SHLW	6.8×10^{2}	3.1×10^{1}	4.9×10^{1}	2.4×10^{3}	7.5×10^{3}	8.5×10^{2}	1.3×10^{3}	2.2×10^{4}
U/PuO_2 Stored	6.7×10^{2}	3.0×10^{1}	4.9×10^{1}	2.3×10^{3}	7.1×10^{3}	8.5×10^{2}	1.3×10^{3}	2.0×10^{4}
					+1000 yr			
U & Pu Recycle	5.5×10^{-1}	5.5×10^{-1}	1.3×10^{-1}	7.2	1.5×10^{1}	1.9	1.4	2.3×10^{2}
U/Pu in SHLW	9.8×10^{-1}	5.2×10^{-1}	1.3×10^{-1}	1.7×10^{1}	3.1×10^{1}	2.0	1.6	5.2×10^{2}
U/PuO_2 Stored	1.9×10^{-1}	4.4×10^{-1}	1.2×10^{-1}	2.4	5.4	7.9×10^{-1}	4.0×10^{-1}	8.2×10^{-1}
					+100,000 yr			
U & Pu Recycle	6.7×10^{-2}	4.4×10^{-1}	5.6×10^{-3}	1.4×10^{-1}	1.5	6.3×10^{-1}	6.1×10^{-2}	3.0
U/Pu in SHLW	1.1	4.2×10^{-1}	1.4×10^{-2}	1.8	2.6×10^{2}	7.7×10^{-1}	1.6×10^{-1}	3.9×10^{1}
U/PuO_2 Stored	3.0×10^{-2}	4.1×10^{-1}	4.7×10^{-3}	7.7×10^{-2}	6.3×10^{-1}	5.8×10^{-1}	5.1×10^{-2}	1.7
					+1,000,000 yr			
U & Pu Recycle	2.2×10^{-2}	4.4×10^{-1}	3.9×10^{-3}	9.8×10^{-2}	4.5×10^{-1}	5.9×10^{-1}	4.2×10^{-2}	2.3
U/Pu in SHLW	2.1×10^{-2}	4.0×10^{-1}	6.9×10^{-3}	4.1×10^{-1}	4.7	5.8×10^{-1}	7.5×10^{-2}	9.6
U/PuO_2 Stored	1.4×10^{-2}	3.9×10^{-1}	3.5×10^{-3}	7.4×10^{-2}	2.8×10^{-1}	5.4×10^{-1}	3.7×10^{-2}	1.9

TABLE 9.3-38. First-Year Dose to the Maximum Individual from Repository Breach by Faulting and Flooding, rem

Recycle Mode	Salt Repository Total Body	Thyroid	Lung	Bone	Nonsalt Repository Total Body	Thyroid	Lung	Bone
					Year 2050			
U & Pu Recycle	5.0×10^{1}	2.4	5.9×10^{1}	9.4	1.7×10^{3}	2.6×10^{1}	2.9×10^{2}	1.9×10^{3}
U/Pu in SHLW	5.0×10^{1}	2.4	6.1×10^{1}	9.2	1.7×10^{3}	2.6×10^{1}	2.8×10^{2}	2.0×10^{3}
U/PuO_2 Stored	5.0×10^{1}	2.4	5.9×10^{1}	9.2	1.7×10^{3}	2.6×10^{1}	2.7×10^{2}	1.9×10^{3}
					+1000 yr			
U & Pu Recycle	8.1×10^{-3}	2.7×10^{-2}	3.5×10^{-3}	6.8×10^{-2}	1.9×10^{-1}	1.3×10^{-1}	2.8×10^{-2}	2.1
U/Pu in SHLW	1.4×10^{-2}	2.5×10^{-2}	3.7×10^{-3}	1.4×10^{-1}	3.8×10^{-1}	1.3×10^{-1}	3.0×10^{-2}	4.5
U/PuO_2 Stored	4.4×10^{-3}	2.5×10^{-2}	2.8×10^{-2}	3.2×10^{-2}	7.3×10^{-2}	1.0×10^{-1}	1.4×10^{-2}	7.9×10^{-1}
					+100,000 yr			
U & Pu Recycle	2.1×10^{-3}	4.9×10^{-2}	8.3×10^{-5}	2.9×10^{-3}	3.1×10^{-2}	1.3×10^{-1}	1.2×10^{-3}	7.9×10^{-2}
U/Pu in SHLW	2.0×10^{-2}	4.5×10^{-2}	2.2×10^{-4}	2.6×10^{-2}	5.1×10^{-1}	1.2×10^{-1}	2.6×10^{-3}	6.3×10^{-1}
U/PuO_2 Stored	6.6×10^{-4}	4.6×10^{-2}	7.7×10^{-5}	1.9×10^{-3}	1.5×10^{-2}	1.2×10^{-1}	1.0×10^{-3}	5.3×10^{-2}
					+1,000,000 yr			
U & Pu Recycle	4.9×10^{-4}	4.6×10^{-2}	6.7×10^{-5}	1.6×10^{-3}	1.0×10^{-2}	1.3×10^{-1}	9.3×10^{-4}	3.6×10^{-2}
U/Pu in SHLW	3.8×10^{-3}	4.3×10^{-2}	6.1×10^{-5}	6.5×10^{-3}	1.0×10^{-2}	1.2×10^{-1}	1.3×10^{-3}	1.5×10^{-1}
U/PuO_2 Stored	3.5×10^{-4}	4.3×10^{-2}	5.6×10^{-5}	1.3×10^{-3}	6.5×10^{-3}	1.2×10^{-1}	7.7×10^{-4}	2.9×10^{-2}

Seventy-year total-body dose commitments to the regional population are presented in Table 9.3-39.

As noted earlier, a breach of repository with surface or groundwater contamination would not likely go unnoticed if it occurred in the year 2050, and measures would be taken to preclude use of the contaminated water. It may be illustrative, however, to examine the effects, assuming

that the contamination did go unnoticed. Thus, the total-body population dose was calculated to be about 4×10^8 man-rem regardless of reprocessing option. Taking the values 100 to 800 health effects per million man-rem, the calculated number of health effects attributable to this accident would amount to about 40,000 to 320,000. The societal risk of such an event may be estimated using the overall expected frequency of faulting and surface transport of activity of 2×10^{-13}/yr (DOE/ET-0028,[1] pg. 7.3.52). Thus, the calculated societal risk would be about 6×10^{-8} health effects. The societal risk associated with death by being struck by lightning may provide some perspective for the societal risk from this breach of repository. The risk of death from lightning in the reference population is about 2×10^6 persons x 0.6 fatalities/1×10^6 persons/yr or 1.2/yr and over 70 years, the societal risk would be 84. In other words, society's risk from such a breach of repository is about 1×10^{-7} that from lightning. Moreover, at such a small societal risk for the assumptions used, an error of several orders of magnitude increase in the leach rates given in Table 9.3-33 would not result in a large risk to society.

At 1000 years (and thereafter) repository closure, it is reasonable to assume that no mitigating procedures may be attempted owing to lack of awareness that water had become contaminated.

TABLE 9.3-39. 70-Year Dose Commitment to the Regional Population - Repository Breach by Faulting and Flooding, man-rem

Recycle Mode	Total Body	Thyroid	Lung	Bone
		Year 2050		
U & Pu Recycle	3.6×10^8	8.6×10^6	1.9×10^7	1.3×10^9
U/Pu in SHLW	3.9×10^8	8.6×10^6	1.9×10^7	1.4×10^9
U/PuO_2 Stored	3.9×10^8	8.6×10^6	1.9×10^7	1.4×10^9
		+1000 yr		
U & Pu Recycle	1.7×10^5	4.8×10^5	9.2×10^4	1.4×10^6
U/Pu in SHLW	2.9×10^5	4.5×10^5	8.7×10^4	4.6×10^6
U/PuO_2 Stored	5.9×10^4	3.9×10^5	2.4×10^4	4.0×10^5
		+100,000 yr		
U & Pu Recycle	2.8×10^4	3.9×10^5	4.2×10^3	6.0×10^4
U/Pu in SHLW	4.2×10^5	3.7×10^5	1.0×10^4	7.1×10^5
U/PuO_2 Stored	1.4×10^4	3.6×10^5	3.5×10^3	3.3×10^4
		+1,000,000 yr		
U & Pu Recycle	1.0×10^4	3.8×10^5	2.8×10^3	4.1×10^4
U/Pu in SHLW	8.2×10^4	3.5×10^5	5.1×10^3	1.7×10^5
U/PuO_2 Stored	7.0×10^3	3.5×10^5	2.5×10^3	3.4×10^4

It should be noted also that one of the long-term effects of release of radionuclides to the R River would include the movement of these radionuclides to the ocean, where accumulation in mollusks may occur, resulting in another pathway to human exposure. It was assumed that the following dilution factors* were applicable for concentrations of elements in an estuary, e.g. concentration of cobalt nuclides in estuary water would be 0.01 of their concentrations in the R River.

Element	Dilution Factor
H	2
C	2
Co	100
Ni	100
Sr	100
Nb, Zr	100
Sb	2
Sn	2
I	2
Cs	100
Sm	100
Eu	100
U	100
Np	100
Pu	100
Am	100
Cm	100

Saltwater bioaccumulation factors were used to estimate the concentration of radionuclides in the edible portion of marine foods.(13) The 70-year dose to the maximum individual from ingestion of mollusks (at a rate of 10 kg/yr) for repository breaches at the year 2050, or 1,000, 100,000, and 1,000,000 years after repository closure, is given in Table 9.3-40.

Based on these factors, the releases from Tables 9.3-34 to 9.3-36 as apportioned for a 50,000 MTHM equivalent repository, and the methods described in Appendix B, 70-year total body doses to the maximum individual from ingestion of 10 kg of mollusk per year were calculated; they are presented in Table 9.3-40.

The largest of these doses, 2.4×10^{-1}, is about 3% of the dose the individual would have received from naturally occurring sources for the same period and would not add significantly to the maximum individual's 70-year dose commitment of about 7×10^{2} rem.

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* Dilution factors are highly dependent on the specific river system and estuary of interest. The dilution factors presented here were developed for movement of radionuclides from reactor effluent water at the Hanford Project in eastern Washington via the Columbia River to Willipa Bay, WA, where oysters are harvested.

TABLE 9.3-40. 70-Year Dose Commitment to the Maximum Individual from Ingestion of Mollusks - Repository Breach by Faulting and Flooding, rem

Recycle Mode	Total Body	Thyroid	Lung	Bone
		Year 2050		
U & Pu Recycle	5.4×10^{-2}	5.5×10^{-3}	4.3×10^{-2}	5.9×10^{-1}
U/Pu in HLW	5.9×10^{-2}	5.1×10^{-3}	5.0×10^{-2}	6.9×10^{-1}
U/PuO_2 Stored	3.7×10^{-2}	5.1×10^{-3}	5.0×10^{-2}	2.7×10^{-1}
		+1,000 yr		
U & Pu Recycle	3.5×10^{-3}	5.5×10^{-3}	2.1×10^{-6}	5.7×10^{-2}
U/Pu in HLW	8.3×10^{-3}	5.1×10^{-3}	1.8×10^{-6}	1.4×10^{-1}
U/PuO_2 Stored	1.2×10^{-3}	5.1×10^{-3}	1.8×10^{-6}	1.8×10^{-2}
		+100,000 yr		
U & Pu Recycle	1.7×10^{-2}	5.4×10^{-3}	1.1×10^{-6}	1.1×10^{-1}
U/Pu in HLW	2.4×10^{-1}	5.1×10^{-3}	9.4×10^{-7}	6.8×10^{-1}
U/PuO_2 Stored	8.5×10^{-3}	5.1×10^{-3}	9.4×10^{-7}	8.2×10^{-2}
		+1,000,000 yr		
U & Pu Recycle	9.9×10^{-3}	5.2×10^{-3}	1.1×10^{-8}	2.0×10^{-1}
U/Pu in HLW	5.9×10^{-2}	4.9×10^{-3}	1.1×10^{-8}	4.3×10^{-1}
U/PuO_2 Stored	1.0×10^{-2}	4.9×10^{-3}	1.1×10^{-8}	1.8×10^{-1}

Total body doses to the regional population for breach of repository in the year 2050 were also calculated for the second- and third-generation population (it is assumed that the entire population is replaced at 70-year intervals). These doses are presented in Table 9.3-41.

TABLE 9.3-41. 70-Year Cumulative Dose to First Three Generations of Regional Population - Repository Breach by Faulting and Flooding, man-rem

Recycle Mode	Total Body	Thyroid	Lung	Bone
		U & Pu Recycle		
Generation 1	3.6×10^{8}	8.6×10^{6}	1.9×10^{7}	1.3×10^{9}
Generation 2	2.0×10^{8}	1.3×10^{7}	1.3×10^{7}	7.8×10^{8}
Generation 3	3.9×10^{7}	3.5×10^{6}	3.5×10^{6}	1.4×10^{8}
		U/Pu in HLW		
Generation 1	3.9×10^{8}	8.6×10^{6}	1.9×10^{7}	1.4×10^{9}
Generation 2	2.4×10^{8}	1.2×10^{7}	1.2×10^{7}	9.3×10^{8}
Generation 3	4.5×10^{7}	2.3×10^{6}	2.8×10^{6}	1.7×10^{8}
		U/PuO_2 Stored		
Generation 1	3.9×10^{8}	8.6×10^{6}	1.9×10^{7}	1.4×10^{9}
Generation 2	2.4×10^{8}	1.2×10^{7}	1.2×10^{7}	9.3×10^{8}
Generation 3	4.4×10^{7}	2.3×10^{6}	2.3×10^{6}	1.7×10^{8}

The dose per generation is decreasing slowly, primarily because of the presence of longer-lived radionuclides in the food chains. At worst, the dose is down to less than that due to naturally occurring sources by the second generation and to about 15% of that by the third generation. As may be recalled from preceding discussions, these consequences will result if the event takes place, but since the event could only result from a combination of improbable events, it is not likely to occur. (Note also that in the year 2050 mitigating efforts could reduce doses to essentially zero.)

The second scenario developed for the repository fracture and flooding assumes that radionuclides are leached from the waste and are transported via slowly moving (100 m/yr) groundwater through the ground before entering the biosphere (the R River). Detailed dose results are presented in Appendix G.

In this scenario only one migration path length (10 km) was investigated, although lengths could vary from a few hundred meters to a few hundred kilometers. Only one groundwater velocity (100 m/yr) was investigated; actual groundwater velocities can vary from essentially zero to over 10,000 m/yr. Perhaps the largest limitation on this scenario is that only one set of sorption equilibrium constants (Kd's) was used. These constants had been measured or estimated for one particular subsoil under one set of conditions at one temperature at the Hanford Site, Richland, Washington. Sorption equilibrium constants can vary over several orders of magnitude for a single element; however, data are not available for other complete subsoils.

Fifty-year accumulated total-body doses to the maximum individual were calculated for various times of repository breach and leach rates and for breach of a repository containing all uranium and plutonium recycle wastes; these doses are presented in Table 9.3-42. The doses do not differ significantly from those calculated for breach of a spent fuel repository except that the long-term dose for ^{226}Ra from decay of ^{238}U is reduced by a factor of about 100 (Section 4.4). This result is about what would be expected based on a ratio of uranium in spent fuel versus the ratio of uranium in recycled wastes. If it can be concluded that the uranium initially in the fuel is indeed burned up in recycling in reactors, there is a cleanup factor of 100 in long-term

TABLE 9.3-42. 50-Year[(a)] Accumulated Total-Body Dose to Maximum Individual for Various Leach Rates and Times of Reprocessing - Waste Repository Breach by Faulting and Groundwater Intrusion (all waste, 379,000 MTHM equivalent, in one repository)

Years Since Disposal	Repository Breach - Year 2050, Leach Rate			Repository Breach - +1,000 Years, Leach Rate			Repository Breach - +100,000 Years, Leach Rate		
	100%/yr	0.1%/yr	0.01%/yr	100%/yr	0.1%/yr	0.01%/yr	100%/yr	0.1%/yr	0.01%/yr
1.1×10^2	2.7×10^2	3.1×10^1	3.1×10^{-2}						
2.2×10^2		2.3							
1.0×10^3	1.9×10^2		2.3×10^{-1}	2.7×10^2	3.1×10^{-1}	3.1×10^2			
2.0×10^3				1.5×10^2	2.1	2.2×10^1			
1.0×10^4	1.8×10^1	1.7		2.1×10^1	2.6	3.0×10^1			
3.4×10^4			3.2×10^{-1}	7.0×10^{-1}	2.6×10^{-1}				
1.1×10^5	1.3	8.0×10^{-1}		1.3			2.0×10^2	2.0×10^{-1}	2.0×10^{-1}
1.4×10^6	3.8	4.0	3.7	5.0	5.5	5.0	5.0	5.5	5.0
5.0×10^6		1.3×10^{-2}							

a. Dose accumulation was set for 50 instead of 70 years in the computer program for making these calculations. If ingestion rates remained constant for the unaccounted 20 years the total dose may be on the order of double that tabulated.

future dose commitments resulting from uranium recycle. If it cannot be concluded that the bulk of the uranium in fuel initially will not return to ground via geologic isolation, there is no advantage for either fuel cycle option in terms of the consequences of this accident scenario.

As long as it is known that a repository exists in a given region, there is little question but that water supplies would be monitored for the presence of radioactive materials following any major earth disturbance. This would be successful for the scenario in which a 2.8 m^3/sec stream developed. In that event, it would probably be possible to divert the entering stream or control use of the water downstream until by confluence with other streams the concentrations of radionuclides resulted in acceptable doses to population groups of interest. In the case of groundwater intrusion, it is unlikely that any mitigating measures could be taken unless the ground water and surface water network of the region was thoroughly monitored for millenia. Such thorough monitoring would seem to be beyond reasonable expectations.

9.3.7 Solution Mining (DOE/ET-0028[1] Accident 7.13)

In this accident a geologic repository in salt is assumed to be breached by solution mining 1000 years after the repository is closed. Although this accident is typified by solution mining for salt recovery, solution mining is also used for extraction of other resources and for construction of underground storage cavities. This accidental breach of a repository is believed to be conceivable only for an industrialized society having technological capabilities substantially the same as exist today.

Basically, solution mining in domed salt involves drilling a well to the desired level in the resource and inserting a double-walled pipe so that water can be forced down the outer pipe into the salt. There the water dissolves the salt into a brine and forces the brine back up the center pipe.[14] In stratified salt a more common practice is to place wells about 500 m apart using water pumped into one well to hydrofracture through the salt to the other well. (This method results in saturated brines being obtained more efficiently.) The brine may then be purified and the salt recovered by several methods, such as the vacuum pan and grainier processes or by solar evaporation of the brine. The life of such solution wells varies markedly, some failing in a few years. For purposes of this accident analysis it is assumed that the well(s) could operate for 50 years before being abandoned because of failure due to cave-in, crushing, and plugging of piping with debris.

This accident, as in the case of the drilling accident, makes the assumption that repository markers are either no longer evident, are misunderstood, or are ignored. No probabilities are assigned to this event and it is presented only as a hypothetical "what if" accident.

Once the brines are brought to the surface, they are analyzed to determine the kinds and amounts of ordinarily encountered impurities such as calcium sulfate, calcium-magnesium carbonate, sulfides, etc., which would govern further processing to purify the salt. It is assumed that although the salt stratum of the reference site is about 80 m thick, the salt removed is principally that from backfill, ceiling, pillars and floor where radioactive waste has been placed. In mining the repository, about 35 million tons of salt were removed for waste placement. This represents about one-fourth of the total salt volume in the mined area (it is assumed that the repository has been backfilled completely with salt; actually backfill of about 60% is presently planned).

The total salt postulated to be solution mined over 50 years is then about 130 million tons.* (This represents about 10% of the total salt contained in the salt strata bounded by the repository area.) Assuming an equal amount of salt is mined in each of 50 years, the annual production would be about 2.6 million tons. (In 1957 about 24 million tons of salt were produced in the United States.)[15] Such a solution mining operation for salt would exceed the size of those presently in operation in the United States; a very large operation in the United States produces about 0.4 million tons annually, and in Europe a very large operation may produce on the order of 1 million tons of salt annually.

The assumption that the entire salt content of the repository is removed by solution mining is somewhat arbitrary. However, in all likelihood, if a waste repository were to be built in salt, the formation would be nearly ideal in all characteristics and as a consequence the formation would likely be attractive for removal of salt by solution mining.

Assuming that 100 parts of water (at 20-100°C) by weight can dissolve 36-39 parts of salt, then over a 50-yr period a stream flow of 3300 gpm is required. Assuming that an adequate source of water is available, nine wells operating at about 370 gpm each would be sufficient.

The actual solution chemistry of leached radionuclides moving into the salt brine is open to question at this writing. For simplicity it is assumed that radionuclides leached from the spent fuel mix completely with the salt brine and are carried to the surface. Although it may take 1/2 to 1-1/2 yr to bring a brine well to production, it is assumed that the brine well produces immediately and continuously for 50 yr, at the end of which the entire quantity of salt surrounding the waste would have been mined out. (It is assumed that water flow would follow a course of least resistance and would follow the previously mined cavern boundaries where possible; this maximizes the consequences.)

The reference LWR scenario places a total of 379,000 MTHM equivalent of spent fuel in six repositories in salt for U and Pu recycle wastes; 10 repositories for U-only recycle wastes where Pu is in HLW; and five repositories for U-only recycle where PuO_2 is stored. Only the removal of wastes associated with U and Pu recycle wastes are analyzed here. The effects from such an accident in the U-only recycle case would be substantially the same as for the U and Pu recycle case (Americium predominates in the determination of dose). It is assumed that the waste is equally distributed among the six repositories so that each repository contains about 63,000 MTHM equivalent.

It is assumed that the waste canisters have been laid bare and that water contacts directly. The rate of leaching radioactivity from solidified high-level waste (waste calcined and in borosilicate glass)** was taken to be 1×10^{-5} g/cm^2-day, adjusted for the density of the

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* Although it is believed that radioanalysis of salt would result in termination of the operation soon after startup, the scenario is developed based on removal of the repository salt over a 50-yr period. Amounts of wastes and salt brought to the surface over shorter periods of time are prorated based on water contact with all wastes by the end of 50 yr. Consequences are based on the assumption that the presence of radioactivity goes undetected for 1 yr.

** In the U & Pu recycle option about one-half of the actinides are in other than high-level waste. However, for simplicity in calculation the total waste actinide inventory was assumed to be in high-level waste.

glass (3 g/cm^3) and for the relationship between the original fuel and the waste in glass (1.8×10^{-5} MTHM spent fuel equivalent/cm^3), which amounted to 6.0×10^{-11} MTHM spent fuel equivalent/cm^2 -day.

Since all the waste is assumed to be contacted by water in 50 yr, the fraction of waste Q contacted by water in one day could be approximated by

$$(50 \times 365)^{-1} Q = 5.5 \times 10^{-5} Q$$

The number of waste-water contact days in the first year would be the sum of

$$(1 + 2 + \ldots 365)\ (5.5 \times 10^{-5})\ Q = 3.7\ Q \text{ days}$$

During any given year the number of contact days, n, would be determined from

$$\frac{n-1}{50}\ 365 + 3.7\ \ Q$$

With 379,000 MTHM in this LWR scenario, the total volume of waste would be 2.1×10^{10} cm^3. For purposes of this calculation it is assumed that the waste in glass is fractured into cubes 1 cm long on a side. The surface area is then 1.3×10^{11} cm^2. In this scenario there are six repositories; hence, the area of waste glass in each repository is 2.1×10^{10} cm^2.

The waste-water contact days for the first year were 3.7; therefore, the amount of waste leached the first year would be (3.7 d) (2.1×10^{10} cm^2) (6.0×10^{-11} MTHM equivalent/cm^2 -d) = 4.7 MTHM. The amount of salt mined was 2.4×10^{12} g; hence, the concentration of waste would be 2.0×10^{-12} MTHM/g salt, and at an ingestion rate of 1800 g/yr about 3.6×10^{-9} MTHM would be ingested in one year.

During purification of salt for culinary or table use a number of techniques are used, and it is believed that much of the waste would be removed by these processes. A decontamination factor of 2×10^{-2} was estimated for removal of americium and plutonium; however, no decontamination factors were used in calculating the consequences of this accident.

If it is assumed that about 3% of the 2.4 million MT of salt mined per year is used in table and culinary salt, then about 72,000 MT would be used for those purposes. Again, assuming 1800 g/yr per person, this amount of salt would provide for about 40 million persons. For purposes of this analysis the exposed population is assumed to consist of 40 million persons.

Although it is expected that daily monitoring controls or tests in the producer's or food processor's quality assurance tests on the salt would bring attention to the presence of contaminated salt (calculations suggest that radioactivity would be determinable with off-the-shelf gamma-ray spectrometer apparatus on samples of a few hundred grams at concentrations of waste in salt existing after a few days of operation and with certainty by one month of operation), it was concluded that a reasonable upper bound on waste entering the food trade would be the waste salt produced in one year. Therefore, the consequences of this accident in terms of

radiation dose to an exposed population of 40 million persons from ingestion of contaminated salt for one year were calculated. The quantities of radionuclides that contributed significantly to total-body dose are listed in Table 9.3-43 and doses are given in Table 9.3-44.

TABLE 9.3-43. Hypothetical Amounts of Radionuclides Ingested with Salt Obtained by Solution Mining from a U & Pu Recycle Waste Repository in Salt; 1-yr Period Beginning in Year 3050, Ci

Nuclide	Ingested Amount, Ci
^{239}Pu	2.2×10^{-8}
^{240}Pu	1.2×10^{-7}
^{241}Am	1.3×10^{-6}
^{243}Am	2.4×10^{-7}

TABLE 9.3-44. 70-Year Total Body Dose Commitment to an Individual from Ingestion of Reprocessing Wastes with 1800 g of Salt - Year 3050, rem

Nuclide	Total Body	GI-LLI[(a)]	Thyroid	Bone
^{129}I	1.2×10^{-6}	5.8×10^{-8}	9.4×10^{-4}	4.2×10^{-7}
^{239}Np	1.6×10^{-8}	5.8×10^{-3}		2.9×10^{-7}
^{239}Pu	5.5×10^{-4}	1.5×10^{-3}		3.4×10^{-2}
^{240}Pu	3.1×10^{-3}	8.1×10^{-3}		2.4×10^{-1}
^{241}Am	8.6×10^{-2}	9.6×10^{-2}		1.4
^{243}Am	1.5×10^{-2}	2.1×10^{-2}		2.7×10^{-1}
Total	1.0×10^{-1}	1.4×10^{-1}	9.4×10^{-4}	1.9

a. Gastrointestinal tract - large lower intestine.

For the assumed exposed population of 40 million persons, the 70-year total body dose commitment would amount to 4.0×10^6 man-rem from such an accident. In terms of an accidental occurrence, these doses are not significant in comparison to the dose of 2.8×10^8 man-rem this population would receive over the same time period from naturally occurring sources.

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10.0 INTEGRATED SYSTEMS FOR COMMERCIAL RADIOACTIVE WASTE MANAGEMENT

10.1 ENVIRONMENTAL EFFECTS ASSOCIATED WITH AN INTEGRATED RADIOACTIVE WASTE MANAGEMENT SYSTEM FOR THE ONCE-THROUGH FUEL CYCLE OPTION - PROMPT DISPOSAL OF SPENT FUEL AS WASTE

10.0 INTEGRATED SYSTEMS FOR COMMERCIAL RADIOACTIVE WASTE MANAGEMENT

In earlier sections, environmental effects related to waste management were presented for individual waste treatment processes and functions and were summed for selected processes that make up waste management systems for reference plants. In this section, environmental effects are further summed for combinations of plants and functions for the light-water reactor power scenarios, 1980 through 2050. The total effects are presented for complete waste management systems* for various light-water reactor fuel cycle options based on a power production of 400 GWe in the year 2000 or a total energy output of about 10,000 GWe-yr.** Socioeconomic effects and accidents (except those related to construction of facilities and transportation) are treated individually for the separate plants and are not included in this section.

The systems for which an analysis of environmental effects were made and are presented are as follows:

- Once-Through Option:
  - prompt disposal of spent fuel
  - decision to dispose of spent fuel deferred until the year 2000
  - disposal facilities unavailable until the year 2000
- Reprocessing for U and Pu Recycle Option:
  - prompt disposal of transuranic wastes
  - decision to reprocess deferred until the year 2000
  - disposal facilities unavailable until the year 2000
- Reprocessing for U-Only Recycle Option:
  - prompt disposal of transuranic waste
  - Pu in high-level waste
  - PuO_2 separated and stored.

10.1 ENVIRONMENTAL EFFECTS ASSOCIATED WITH AN INTEGRATED RADIOACTIVE WASTE MANAGEMENT SYSTEM FOR THE ONCE-THROUGH FUEL CYCLE OPTION - PROMPT DISPOSAL OF SPENT FUEL AS WASTE

In the reference once-through fuel cycle option, spent fuel will not be reprocessed and is considered as a waste. It will be removed from reactors and placed in reactor spent fuel storage basins for a minimum of one-half year. Because of thermal considerations in dry packaging, spent fuel is assumed to be cooled for 6 to 7 years before packaging and delivery to a federal waste repository. It is assumed that 25% of all reactors will not have enough onsite storage capacity to cool spent fuel for this length of time.*** Thus fuel from these reactors will be shipped to an independent spent fuel storage facility (ISFSF) for storage prior to packaging.

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* Non-transuranic wastes are not considered in this report.

** Radiological effects of a low growth scenario that produced 6500 7 kWe-yr were investigated. Results are presented in Tables D-42 to D-51, Appendix D. The ratio of radiological effects over the total scenario is about 1.6:1, where as the power generation ratio is about 1.5:1 for the reference to the low power growth scenario. Therefore, the integrated radiological impact for power scenarios between 6500 GWe-yr and 10,000 GWe-yr can be estimated by multiplying the impact at 10,000 GWe-yr by the ratio of the power scenario of interest to 10,000 GWe-yr.

*** In this report only the dose associated with off gas from storage of spent fuel at the ISFSF is considered. In Appendix D the dose associated with off gas at reactor storage basins is also included in system totals.

After cooling 6 to 7 years at the reactors, the other 75% of the reactor fuel will be sent to the ISFSF for packaging. This option assumes that spent fuel will always be considered to be a waste and that retrieval of spent fuel as a resource from geologic repositories will not occur. (Retrievability to ensure against possible unacceptability of the repository is, however, a contingency for about 5 years.) Waste flow from the once-through option is illustrated in Figure 10.1-1.

Plants and/or functions for which environmental impacts of management of radioactive wastes are considered in the reference once-through option are (in order from the reactor):

- transport of spent fuel to the ISFSF for storage and packaging
- interim storage (6 years) for 25% of the spent fuel
- packaging of all spent fuel for isolation
- rail transport of packaged spent fuel to a waste repository
- isolation at a geologic waste isolation repository.

Reactors are assumed to be located 1600 km from an ISFSF with packaging capability. It is further assumed that a federal geologic waste repository is located 2400 km from an ISFSF. In the reference case, 90% of the spent fuel is transported from reactors to ISFSFs by rail and 10% is transported by truck. All packaged spent fuel is shipped by rail from the ISFSF to the waste repository.

In the reference system used for this analysis, over the 1980 to 2050 time period about 89,000 shipments of spent fuel are made by rail and about 89,000 shipments are made by truck to spent fuel storage basins. About 120,000 rail shipments are required to transport packaged fuel on to the waste repository. The total distance traveled by rail casks amounts to about 860 million km, and about 2800 million km by truck casks. These are round-trip distances since it is assumed that casks will need to be returned for reuse.

It will be necessary to construct eight 30-year-life ISFSFs with packaging facilities to provide the required storage and packaging of spent fuel. For the reference once-through integrated system, eight repositories in salt, three repositories in granite, six repositories in shale, or three repositories in basalt are required for isolation of spent fuel generated through the year 2040. It is assumed that these facilties are located in the same 80-km radius region. This assumption is made to simplify dose calculations and to maximize radiological consequences. In practice it would not be likely that all of the facilities would be located in the same region. Water use and ecological impacts assume that all facilities are not colocated.

10.1.1 Environmental Effects Related to Construction of the Integrated Waste Management System

Environmental impacts of construction of a once-through integrated system relate principally to resource commitments and pollutants released from plant vehicles and fugitive dust from surface piles of mined material at the repositories.

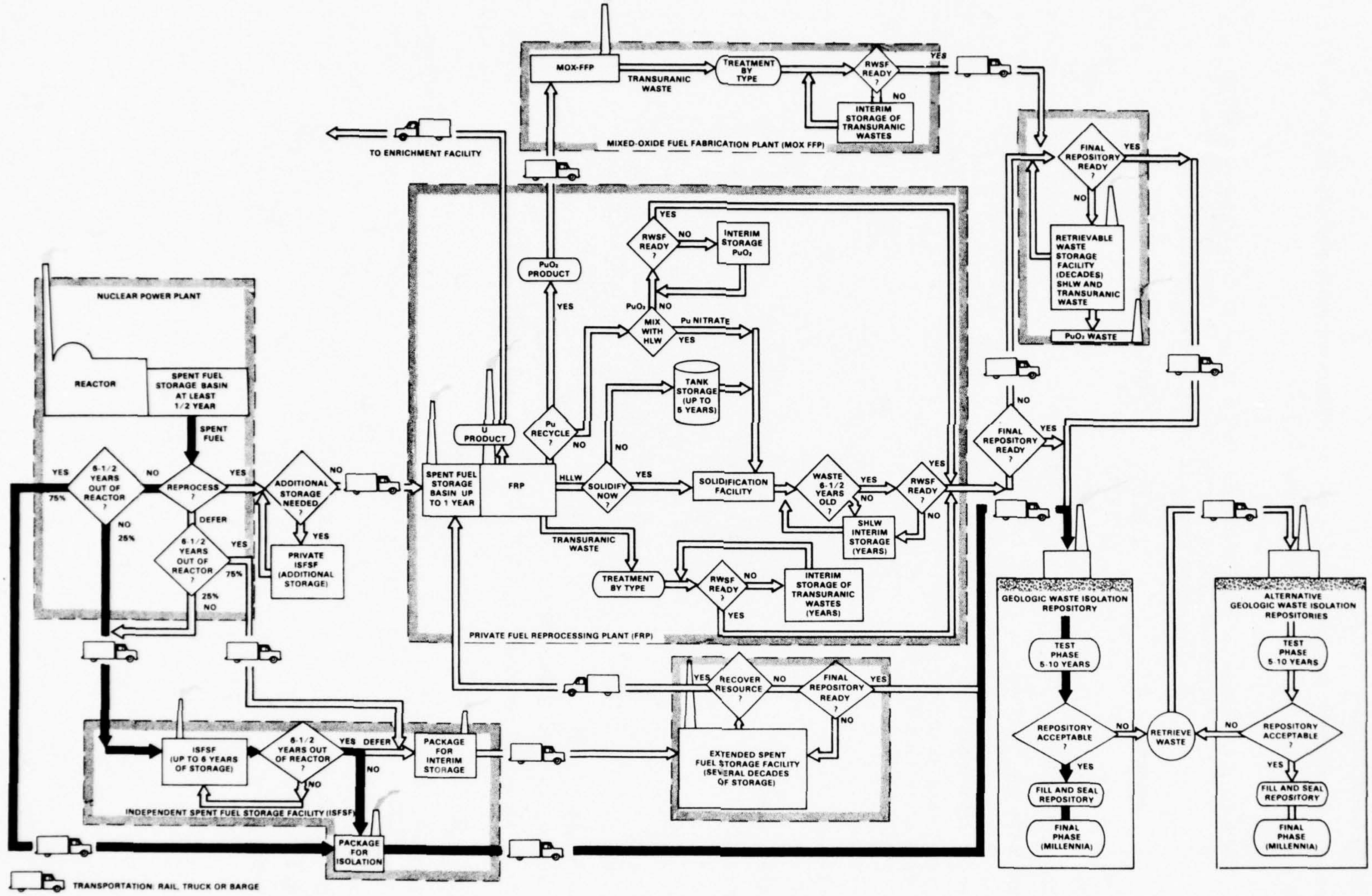

FIGURE 10.1-1. Flow of Spent Fuel (Outlined in Black) in the Once-Through Fuel Cycle Option

Resource Commitments

Resource commitments for construction of the integrated waste management system from 1980 to 2050 are summarized in Tables 10.1-1 through 10.1-4.

TABLE 10.1-1. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050, with Prompt Disposal in Salt Repositories

Resource	8 ISFSFs	Transportation	8 Repositories	Total
Water, m^3	8.0×10^5		1.9×10^6	2.7×10^6
Land, ha				
Surface facilities	8.0×10^1		1.4×10^3	1.4×10^3
Access roads and railroads	1.1×10^2		6.4×10^1	1.7×10^2
Mineral and surface rights (fenced restricted area)	3.2×10^3		6.5×10^3	9.7×10^3
Additional land on which only sub-surface activities will be restricted	--		2.6×10^4	2.6×10^4
Materials				
Concrete, m^3	3.7×10^5		8.0×10^5	1.2×10^6
Steel, MT	1.2×10^5		1.3×10^5	2.5×10^5
Stainless steel, MT	4.9×10^4	4.0×10^3		5.3×10^4
Copper, MT	3.6×10^2		1.8×10^3	2.2×10^3
Zinc, MT	5.2×10^2		4.4×10^2	9.6×10^2
Aluminum, MT			3.3×10^2	3.3×10^2
Lumber, m^3	2.6×10^4		1.8×10^4	4.4×10^4
Lead, MT		6.9×10^3	--	6.9×10^3
Depleted uranium, MT		2.8×10^3	--	2.8×10^3
Chromium in stainless steel, MT		7.6×10^2	--	7.6×10^2
Nickel in stainless steel, MT		4.0×10^2	--	4.0×10^2
Energy				
Propane, m^3	7.6×10^3		1.8×10^4	2.6×10^4
Diesel fuel, m^3	7.6×10^4		1.8×10^5	2.6×10^5
Gasoline, m^3	5.1×10^4		1.3×10^5	1.8×10^5
Electricity				
Peak demand, kWh	2.2×10^4		2.7×10^4	4.9×10^4
Total consumption, kWh	3.7×10^7		1.1×10^8	1.5×10^8
Manpower, man-yr	3.2×10^4		8.0×10^4	1.1×10^5

TABLE 10.1-2. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050, with Prompt Disposal in Granite Repositories

Resource	8 ISFSFs	Transportation	3 Repositories	Total
Water, m^3	8.0×10^5		2.1×10^6	2.9×10^6
Land, ha				
Surface facilities	8.0×10^1		8.4×10^2	9.2×10^2
Access roads and railroads	1.1×10^2		2.4×10^1	1.3×10^2
Mineral and surface rights (fenced restricted area)	3.2×10^3		2.4×10^3	5.6×10^3
Additional land on which only subsurface activities will be restricted	--		9.6×10^3	9.6×10^3
Materials				
Concrete, m^3	3.7×10^5		9.0×10^5	1.3×10^6
Steel, MT	1.2×10^5		1.4×10^5	2.6×10^5
Stainless steel, MT	4.9×10^4	4.0×10^3	--	5.3×10^4
Copper, MT	3.6×10^2		2.0×10^3	2.4×10^3
Zinc, MT	5.2×10^2		4.8×10^2	1.0×10^3
Aluminum, MT	--		3.6×10^2	3.6×10^2
Lumber, m^3	2.6×10^4		2.1×10^4	4.7×10^4
Lead, MT		6.9×10^3	--	6.9×10^3
Depleted uranium, MT		2.8×10^3	--	2.8×10^3
Chromium in stainless steel, MT		7.6×10^2	--	7.6×10^2
Nickel in stainless steel, MT		4.0×10^2	--	4.0×10^2
Energy				
Propane, m^3	7.6×10^3		1.9×10^4	2.7×10^4
Diesel fuel, m^3	7.6×10^4		1.9×10^5	2.7×10^5
Gasoline, m^3	5.1×10^4		1.4×10^5	1.9×10^5
Electricity				
Peak demand, kWh	2.2×10^4		3.3×10^4	5.5×10^4
Total consumption, kWh	3.7×10^7		1.3×10^8	1.7×10^8
Manpower, man-yr	3.2×10^4		9.0×10^4	1.2×10^5

Nonradiological Effluents

Effluents from construction of the integrated system facilities will include dust generated from construction of surface facilities, dust from rocks (salt, granite, shale, and basalt) brought to the surface during repository mining, and pollutants from operation of machinery. Dust from mining and transport within the mine is removed by filters in the mine ventilation

TABLE 10.1-3. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050, with Prompt Disposal in Shale Repositories

Resource	8 ISFSFs	Transportation	6 Repositories	Total
Water, m^3	8.0×10^5		2.2×10^6	3.0×10^6
Land, ha				
Surface facilities	8.0×10^1		1.1×10^3	1.1×10^3
Access roads and railroads	1.1×10^2		4.8×10^1	1.6×10^2
Mineral and surface rights (fenced restricted area)	3.2×10^3		4.9×10^3	8.1×10^3
Additional land on which only sub-surface activities will be restricted	--		1.9×10^4	1.9×10^4
Materials				
Concrete, m^3	3.7×10^5		9.0×10^5	1.3×10^6
Steel, MT	1.2×10^5		1.4×10^5	2.6×10^5
Stainless steel, MT	4.9×10^4	4.0×10^3	--	5.3×10^4
Copper, MT	3.6×10^2		2.0×10^3	2.4×10^3
Zinc, MT	5.2×10^2		4.8×10^2	1.0×10^3
Aluminum, MT			3.8×10^2	3.8×10^2
Lumber, m^3	2.6×10^4		1.8×10^4	4.4×10^4
Lead, MT		6.9×10^3	--	6.9×10^3
Depleted uranium, MT		2.8×10^3	--	2.8×10^3
Chromium in stainless steel, MT		7.6×10^2	--	7.6×10^2
Nickel in stainless steel, MT		4.0×10^2	--	4.0×10^2
Energy				
Propane, m^3	7.6×10^3		1.9×10^4	2.7×10^4
Diesel fuel, m^3	7.6×10^4		1.9×10^5	2.7×10^5
Gasoline, m^3	5.1×10^4		1.3×10^5	1.8×10^5
Electricity				
Peak demand, kWh	2.2×10^4		3.1×10^4	5.3×10^4
Total consumption, kWh	3.7×10^7		1.3×10^8	1.7×10^8
Manpower, man-yr	3.2×10^4		8.4×10^4	1.2×10^5

system; surface handling and transport of mined materials is expected to result in the greatest dust generation. Maximum dust emissions per day from surface handling of mined materials are presented in Table 10.1-5 for the four geologic media.

The maximum and average concentrations of dust resulting from surface storage were calculated at the fenceline (1.6 km) for one repository. These concentrations are presented in Table 10.1-6 for the four geologic media.

TABLE 10.1-4. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050, with Prompt Disposal in Basalt Repositories

Resource	8 ISFSFs	Transportation	3 Repositories	Total
Water, m^3	8.0×10^5		1.8×10^6	2.6×10^6
Land, ha				
Surface facilities	8.0×10^1		8.4×10^2	9.2×10^2
Access roads and railroads	1.1×10^2		2.4×10^1	1.3×10^2
Mineral and surface rights (fenced restricted area)	3.2×10^3		2.4×10^3	5.6×10^3
Additional land on which only subsurface activities will be restricted	--		9.6×10^3	9.6×10^3
Materials				
Concrete, m^3	3.7×10^5		7.5×10^5	1.1×10^6
Steel, MT	1.2×10^5		1.2×10^5	2.4×10^5
Stainless steel, MT	4.9×10^4	4.0×10^3	--	5.3×10^4
Copper, MT	3.6×10^2		1.7×10^3	2.1×10^3
Zinc, MT	5.2×10^2		4.2×10^2	9.4×10^2
Aluminum, MT			3.3×10^2	3.3×10^2
Lumber, m^3	2.6×10^4		1.8×10^4	4.4×10^4
Lead, MT		6.9×10^3	--	6.9×10^3
Depleted uranium, MT		2.8×10^3	--	2.8×10^3
Chromium in stainless steel, MT		7.6×10^2	--	7.6×10^2
Nickel in stainless steel, MT		4.0×10^2	--	4.0×10^2
Energy				
Propane, m^3	7.6×10^3		1.6×10^4	2.4×10^4
Diesel fuel, m^3	7.6×10^4		1.6×10^5	2.4×10^5
Gasoline, m^3	5.1×10^4		1.2×10^5	1.7×10^5
Electricity				
Peak demand, kWh	2.2×10^4		2.6×10^4	4.8×10^4
Total consumption, kWh	3.7×10^7		1.1×10^8	1.5×10^8
Manpower, man-yr	3.2×10^4		1.1×10^5	1.4×10^5

TABLE 10.1-5. Maximum Dust Emissions From Surface Handling of Mined Material, MT/d

	Repository Medium			
Climate	Salt	Granite	Shale	Basalt
Reference	3.1	7.9	3.7	9.3
Arid	44	110	51	130

TABLE 10.1-6. Dust Concentrations at Repository Fenceline, $\mu g/m^3$

Repository Medium	Maximum	Average
Salt		
Reference	110	66
Arid	1400	790
Granite		
Reference	290	170
Arid	3500	2100
Shale		
Reference	130	79
Arid	1600	930
Basalt		
Reference	330	190
Arid	4100	2400

The primary federal air quality standard for suspended particulate matter computed as an annual geometric mean is 75 $\mu g/m^3$. Thus, for both the reference site and any proposed arid site, there would be a degradation of air quality without application of appropriate control techniques during surface handling of mined material.

To give perspective to the salt concentrations (in Table 10.1-6) at the repository fenceline, it may be noted that particulate concentrations of salt near the shore on the eastern seaboard average about 140 $\mu g/m^3$ at 0.5 km inland and about one-tenth of that 1 km inland. During persistently high onshore winds the concentration may be on the or 380 $\mu g/m^3$ at 0.5 km and 60 $\mu g/m^3$ at 1 km.[1]

Containment of salt brought to the surface will require thorough analysis if and when site-specific projects are developed. It is possible that if salt brought to the surface is not properly managed, the result could be the most serious environmental impact associated with the waste repository. Covering the salt piles with asphalt paving has been suggested to preclude dispersal of salt dust in arid climates. It would also be possible to remove the salt stored on the surface and dispose of it by use in industry, placement in other mines, dispersion at sea, etc. Managing the salt is not an insurmountable problem and probably has several practical solutions.

About 2.7 x 10^5 m^3 of fossil fuel will be needed to supply energy during construction of the integrated system facilities. Burning of this quantity of fuel over the construction period will result in air pollutant emissions, but calculated concentrations of pollutants in air at facility fencelines are not expected to result in air quality effects outside the regulatory

limits. Estimates of other pollutants released to the atmosphere from operating equipment during construction are given in Tables 10.1-7 through 10.1-10. These quantities are developed from the total quantities of fuel burned and emission factors for a given effluent.[2]

TABLE 10.1-7. Total Quantities of Effluents Released to the Atmosphere During Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option - Salt Repository

Pollutant	8 ISFSFs	8 Repositories	Total
Carbon monoxide, MT	1.3×10^4	6.3×10^4	7.6×10^4
Hydrocarbons, MT	6.2×10^2	2.9×10^3	3.5×10^3
Nitrogen oxide, MT	2.6×10^3	1.2×10^4	1.5×10^4
Sulfur oxide, MT	1.7×10^2	7.4×10^2	9.1×10^2
Particulates, MT	1.3×10^4	7.5×10^2	1.4×10^4

TABLE 10.1-8. Total Quantities of Effluents Released to the Atmosphere During Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option - Granite Repository

Pollutant	8 ISFSFs	3 Repositories	Total
Carbon monoxide, MT	1.3×10^4	6.9×10^4	8.2×10^4
Hydrocarbons, MT	6.2×10^2	3.3×10^3	3.9×10^3
Nitrogen oxide, MT	2.6×10^3	1.4×10^4	1.7×10^4
Sulfur oxide, MT	1.7×10^2	8.1×10^2	9.8×10^2
Particulates, MT	1.3×10^4	8.1×10^2	1.4×10^4

TABLE 10.1-9. Total Quantities of Effluents Released to the Atmosphere During Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option - Shale Repository

Pollutant	8 ISFSFs	6 Repositories	Total
Carbon monoxide, MT	1.3×10^4	6.0×10^4	7.3×10^4
Hydrocarbons, MT	6.2×10^2	2.9×10^3	3.5×10^3
Nitrogen oxide, MT	2.6×10^3	1.3×10^4	1.6×10^4
Sulfur oxide, MT	1.7×10^2	7.8×10^2	9.5×10^2
Particulates, MT	1.3×10^4	7.8×10^2	1.4×10^4

Ecological Effects

Construction activities at the integrated system facilities will involve the removal of vegetation and displacement of birds and small mammals from the site areas. Weedy species of plants will invade cleared areas unless revegetation practices are applied. Localized dust problems will occur until vegetation cover is re-established.

TABLE 10.1-10. Total Quantities of Effluents Released to the Atmosphere During Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option - Basalt Repository

Pollutant	8 ISFSFs	3 Repositories	Total
Carbon monoxide, MT	1.3×10^4	6.0×10^4	7.3×10^4
Hydrocarbons, MT	6.2×10^2	2.7×10^3	3.3×10^3
Nitrogen oxide, MT	2.6×10^3	1.1×10^4	1.4×10^4
Sulfur oxide, MT	1.7×10^2	6.9×10^2	8.6×10^2
Particulates, MT	1.3×10^4	6.9×10^2	1.4×10^4

The major ecological impact would result from depositions of salt dust from unmanaged salt piles, since fenceline, ground-level concentrations for salt dust released from surface storage and handling operations were calculated to exceed acceptable levels. Estimates of 8.4 and 84 g/m^2-yr respectively for the reference and arid climates were made for salt depositions at the repository fenceline. These deposition rates are in the range of 4.5 to 94.5 g/m^2-yr, which produces observable leaf burn on plants such as beans. Based on the assumptions made for determining salt depositions, salt pile management procedures would be needed to reduce salt dispersal at least two orders of magnitude. This reduction would ensure that emission concentrations are well below toxic levels. Once contaminated, soils affected by salt will require special remedial measures and management practices to restore them to their original productivity. The potential also exists for salt deposited as dust on the land to be transported by runoff to nearby surface waters. The possibility exists for surface waters, particularly shallow catch-basin types of ponds, to receive amounts of salt sufficient to damage indigenous aquatic plants and animals. There is also the possiblity that resident species would be replaced by more salt-tolerant forms.

The direct effects of salt on animals are not generally considered significant. However, loss of vegetation caused by the effects of salt would reduce cover and food supplies for mammals and birds and would result in their displacement or elimination. Loss of vegetation would also limit the use of vegetation to increase the aesthetic qualitites of the storage area and to control dust.

Soil erosion control measures will be needed to prevent surface runoff from adding suspended solids to nearby land and surface waters. Assuming use of only reasonably good practices, the effects on aquatic biota resulting from construction of the integrated system facilities will be negligible.

Accidents

Injuries and fatalities forecasted for construction of waste management facilities through the year 2050 are presented in Tables 10.1-11 through 10.1-14 for the four geologic media. Injury rates of 13.6 disability injuries per million man-hr for surface construction and 25 disabling injuries per million man-hr for underground mining were used. For fatality predictions fatality rates of 0.17 fatalities per million man-hr[3] for surface construction and 0.53 fatalities per million man-hr for underground mining were used.

Resource Commitments

Resources needed during planned operation of integrated system facilities over the 70-year period ending in 2050 are listed in Tables 10.1-15 through 10.1-18.

TABLE 10.1-15. Resources Required During Planned Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - Prompt Disposal in Salt Repositories

Resource	8 ISFSFs	Transportation	8 Repositories	Total
Materials				
Steel, MT				
PWR canister overpacks			2.0×10^2	2.0×10^2
BWR canister overpacks			2.2×10^2	2.2×10^2
PWR retrievability sleeves			7.0×10^4	7.0×10^4
BWR retrievability sleeves			8.0×10^4	8.0×10^4
Packaging canisters and overpacks	3.1×10^5			3.1×10^5/ 4.6×10^5
Concrete, MT			1.2×10^5	1.2×10^5
5% NaOH, m^3	1.4×10^5			1.4×10^5
5% HNO_3, m^3	9.1×10^4			9.1×10^4
Detergent, m^3	6.7×10^3			6.7×10^3
Helium, m^3	2.6×10^5			2.6×10^5
Water consumed, m^3	6.0×10^7			6.0×10^7
Energy				
Electricity, kWh	8.2×10^9		1.2×10^{10}	2.0×10^{11}
Coal, MT	2.1×10^6		9.6×10^6	1.2×10^7
Diesel fuel, m^3		2.1×10^6	1.7×10^6	3.8×10^6
Steam, MT			1.0×10^8	1.0×10^8
Manpower, man-yr	3.8×10^4	9.6×10^3	8.8×10^4	1.4×10^5

Process Effluents

Nonradioactive effluents released to the biosphere over the 70-year period ending in 2050 are listed in Tables 10.1-19 through 10.1-22.

For comparison, the emissions from space heaters in a town of 30,000 were estimated for the same 70-year period. Assuming that furnace oil was the fuel and that it had a sulfur content of 1%, the following total emissions were calculated:

Particulates, MT	1.6×10^3
Sulfur oxide, MT	2.1×10^4
Carbon monoxide, MT	7.7×10^2
Hydrocarbons, MT	4.2×10^2
Nitrogen oxide, MT	1.9×10^3

TABLE 10.1-11. Nonradiological Injuries and Fatalities Associated with Construction of the Integrated Radioactive Waste Management System for the Once-Through Fuel Cycle Option Through 2050 - for Prompt Disposal in Salt Repositories

	8 ISFSFs	Transportation	8 Repositories	Total
Injuries	880	430	3500	4800
Fatalities	11	47	72	130

TABLE 10.1-12. Nonradiological Injuries and Fatalities Associated with Construction of the Integrated Radioactive Waste Management System for the Once-Through Fuel Cycle Option Through 2050 - for Prompt Disposal in Granite Repositories

	8 ISFSFs	Transportation	3 Repositories	Total
Injuries	880	430	4500	5800
Fatalities	11	47	93	150

TABLE 10.1-13. Nonradiological Injuries and Fatalities Associated with Construction of the Integrated Radioactive Waste Management System for the Once-Through Fuel Cycle Option Through 2050 - for Prompt Disposal in Shale Repositories

	8 ISFSFs	Transportation	6 Repositories	Total
Injuries	880	430	3900	5200
Fatalities	11	47	78	140

TABLE 10.1-14. Nonradiological Injuries and Fatalities Associated with Construction of the Integrated Radioactive Waste Management System for the Once-Through Fuel Cycle Option Through 2050 - for Prompt Disposal in Basalt Repositories

	8 ISFSFs	Transportation	3 Repositories	Total
Injuries	880	430	5400	6700
Fatalities	11	47	110	170

Depending on the geologic medium, 60-75% of the disabling injuries for the integrated system will be due to underground mining. Between 50-65% of the fatalities will be due to underground mining at the repository. No disabling injuries or fatalities will occur as a direct result of radiation.

10.1.2 *Environmental Effects Related to Operation of the Integrated Waste Management System*

The operational phase of the integrated waste management system for the once-through fuel cycle option will include the receiving, handling, packaging, transport, and placement of spent fuel elements into proper subterranean storage areas. Mining operations will continue and storage areas for tailings will be required. The maximum storage capacity of the repositories will be reached after approximately 16, 25, 18, and 25 years of operation,* respectively, for the salt, granite, shale, and basalt repositories. Other facilities will operate for 30 years.

* Before closure and decommissioning.

TABLE 10.1-16. Resources Required During Planned Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - Prompt Disposal in Granite Repositories

Resource	8 ISFSFs	Transportation	3 Repositories	Total
Materials				
Steel, MT				
PWR canister overpacks			1.6×10^2	1.6×10^2
BWR canister overpacks			1.9×10^2	1.9×10^2
PWR retrievability sleeves			2.6×10^4	2.6×10^4
BWR retrievability sleeves			4.2×10^5	4.2×10^5
Packaging canisters and overpacks	3.1×10^5			3.1×10^5/ 7.6×10^5
Concrete, MT			4.5×10^4	4.5×10^4
5% NaOH, m^3	1.4×10^5			1.4×10^5
5% HNO_3, m^3	9.1×10^4			9.1×10^4
Detergent, m^3	6.7×10^3			6.7×10^3
Helium, m^3	2.6×10^5			2.6×10^5
Water consumed, m^3	6.0×10^7			6.0×10^7
Energy				
Electricity, kWh	8.2×10^9		9.6×10^9	1.8×10^{10}
Coal, MT	2.1×10^6		5.4×10^6	7.5×10^6
Diesel fuel, m^3		2.1×10^6	9.6×10^5	3.1×10^6
Steam, MT			6.0×10^7	6.0×10^7
Manpower, man-yr	3.8×10^4	9.6×10^3	6.0×10^4	1.1×10^5

TABLE 10.1-17. Resources Required During Planned Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - Prompt Disposal in Shale Repositories

Resource	8 ISFSFs	Transportation	6 Repositories	Total
Materials				
Steel, MT				
PWR canister overpacks			1.7×10^2	1.7×10^2
BWR canister overpacks			2.2×10^2	2.2×10^2
PWR retrievability sleeves			5.3×10^4	5.3×10^4
BWR retrievability sleeves			6.0×10^4	6.0×10^4
Packaging canisters and overpacks	3.1×10^5			3.1×10^5/ 4.2×10^5
Concrete, MT			8.9×10^4	8.9×10^4
5% NaOH, m^3	1.4×10^5			1.4×10^5
5% HNO_3, m^3	9.1×10^4			9.1×10^4
Detergent, m^3	6.7×10^3			6.7×10^3
Helium, m^3	2.6×10^5			2.6×10^5
Water consumed, m^3	6.0×10^7			6.0×10^7
Energy				
Electricity, kWh	8.2×10^9		1.0×10^{10}	1.8×10^{10}
Coal, MT	2.1×10^6		7.8×10^6	9.9×10^6
Diesel fuel, m^3		2.1×10^6	1.4×10^6	3.5×10^6
Steam, MT			8.4×10^7	8.4×10^7
Manpower, man-yr	3.8×10^4	9.6×10^3	7.8×10^4	1.3×10^5

TABLE 10.1-18. Resources Required During Planned Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - Prompt Disposal in Basalt Repositories

Resource	8 ISFSFs	Transportation	3 Repositories	Total
Materials				
Steel, MT				
PWR canister overpacks			1.6×10^2	1.6×10^2
BWR canister overpacks			1.9×10^2	1.9×10^2
PWR retrievability sleeves			2.6×10^4	2.6×10^4
BWR retrievability sleeves			4.2×10^5	4.2×10^5
Packaging canisters and overpacks	3.1×10^5			3.1×10^5/ 7.6×10^5
Concrete, MT			4.5×10^4	4.5×10^4
5% NaOH, m^3	1.4×10^5			1.4×10^5
5% HNO_3, m^3	9.1×10^4			9.1×10^4
Detergent, m^3	6.7×10^3			6.7×10^3
Helium, m^3	2.6×10^5			2.6×10^5
Water consumed, m^3	6.0×10^7			6.0×10^7
Energy				
Electricity, kWh	8.2×10^9		9.6×10^9	1.8×10^{10}
Coal, MT	2.1×10^6		5.4×10^6	7.5×10^6
Diesel fuel, m^3		2.1×10^6	9.6×10^5	3.1×10^6
Steam, MT			6.0×10^7	6.0×10^7
Manpower, man-yr	3.8×10^4	9.6×10^3	5.7×10^4	1.0×10^5

TABLE 10.1-19. Nonradioactive Effluents Released During the 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Salt Repositories

Effluent	8 ISFSFs	Transportation	8 Repositories	Total
Particulates, MT		5.4×10^3	3.4×10^3	8.7×10^3
Sulfur oxides, MT		1.2×10^4	7.8×10^4	9.0×10^4
Carbon monoxide, MT		3.6×10^4	1.9×10^4	5.5×10^4
Hydrocarbons, MT		2.9×10^4	7.0×10^3	3.6×10^4
Nitrogen oxides, MT		8.0×10^4	1.2×10^5	2.0×10^5
Aldehydes, MT		1.1×10^3		1.1×10^3
Organic acids, MT		1.4×10^3		1.4×10^3
Heat, MJ	1.2×10^3		3.1×10^9	3.1×10^9
Water, m^3				
Blowdown from cooling tower	8.4×10^6			8.4×10^6
Drift from cooling tower	2.4×10^5			2.4×10^5

TABLE 10.1-20. Nonradioactive Effluents Released During the 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Granite Repositories

Effluent	8 ISFSFs	Transportation	3 Repositories	Total
Particulates, MT		5.4×10^3	2.1×10^3	7.5×10^3
Sulfur oxides, MT		1.2×10^4	4.5×10^4	5.7×10^4
Carbon monoxide, MT		3.6×10^4	1.1×10^4	4.7×10^4
Hydrocarbons, MT		2.9×10^4	4.2×10^3	3.3×10^4
Nitrogen oxides, MT		8.0×10^4	7.2×10^4	1.5×10^5
Aldehydes, MT		1.1×10^3		1.1×10^3
Organic acids, MT		1.4×10^3		1.4×10^3
Heat, MJ	1.2×10^3		2.8×10^9	2.8×10^9
Water, m^3				
Blowdown from cooling tower	8.4×10^6			8.4×10^6
Drift from cooling tower	2.4×10^5			2.4×10^5

TABLE 10.1-21. Nonradioactive Effluents Released During the 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Shale Repositories

Effluent	8 ISFSFs	Transportation	6 Repositories	Total
Particulates, MT		5.4×10^3	2.9×10^3	8.3×10^3
Sulfur oxides, MT		1.2×10^4	6.6×10^4	7.8×10^4
Carbon monoxide, MT		3.6×10^4	1.6×10^4	5.2×10^4
Hydrocarbons, MT		2.9×10^4	5.9×10^3	3.5×10^4
Nitrogen oxides, MT		8.0×10^4	1.0×10^5	1.8×10^5
Aldehydes, MT		1.1×10^3		1.1×10^3
Organic acids, MT		1.4×10^3		1.4×10^3
Heat, MJ	1.2×10^3		2.9×10^9	2.9×10^9
Water, m^3				
Blowdown from cooling tower	8.4×10^6			8.4×10^6
Drift from cooling tower	2.4×10^5			2.4×10^5

Physical, Chemical, and Thermal Effects

For individual facilities, the releases of pollutants would not in any case result in federal air quality standards being exceeded at the respective plant boundaries.

Routine releases of radioactive material from the integrated waste management facilities will consist of naturally occurring radon and its decay products released form the repository and radionuclides released from spent fuel storage and packaging facilities. Direct radiation will emanate from spent fuel during transport from one facility to another. Radionuclides released to the biosphere annually are listed in Tables 10.1-23 through 10.1-26.

TABLE 10.1-22. Nonradioactive Effluents Released During the 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Basalt Repositories

Effluent	8 ISFSFs	Transportation	3 Repositories	Total
Particulates, MT		5.4×10^3	2.0×10^3	7.4×10^3
Sulfur oxides, MT		1.2×10^4	4.5×10^4	5.7×10^4
Carbon monoxide, MT		3.6×10^4	1.1×10^4	4.7×10^4
Hydrocarbons, MT		2.9×10^4	4.2×10^3	3.3×10^4
Nitrogen oxides, MT		8.0×10^4	7.2×10^4	1.5×10^5
Aldehydes, MT		1.1×10^3		1.1×10^3
Organic acids, MT		1.4×10^3		1.4×10^3
Heat, MJ	1.2×10^3		2.8×10^9	2.8×10^9
Water, m^3				
Blowdown from cooling tower	8.4×10^6			8.4×10^6
Drift from cooling tower	2.4×10^5			2.4×10^5

TABLE 10.1-23. Radionuclides Released to the Biosphere from 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Salt Repositories

Radionuclides	8 ISFSFs	8 Repositories	Total
^{3}H	1.4×10^3		1.4×10^3
^{14}C	2.4		2.4
^{58}Co	1.5×10^{-1}		1.5×10^{-1}
^{60}Co	5.3×10^{-1}		5.3×10^{-1}
^{85}Kr	4.1×10^5		4.1×10^5
^{90}Sr	9.8×10^{-2}		9.8×10^{-2}
^{91}Y	7.0×10^{-2}		7.0×10^{-2}
^{95}Zr	4.1×10^{-1}		4.1×10^{-1}
^{95}Nb	7.2×10^{-1}		7.2×10^{-1}
^{106}Ru	3.1×10^{-1}		3.1×10^{-1}
^{125m}Te	3.4×10^{-3}		3.4×10^{-3}
^{127m}Te	3.1×10^{-3}		3.1×10^{-3}
^{129}I	2.4×10^{-1}		2.4×10^{-1}
^{134}Cs	4.6		4.6
^{137}Cs	5.5		5.5
^{144}Ce	5.3×10^{-1}		5.3×10^{-1}
^{220}Rn		7.4×10^{-3}	7.4×10^{-3}
^{222}Rn		1.0×10^{-2}	1.0×10^{-2}
^{210}Pb		8.8×10^{-7}	8.8×10^{-7}
^{212}Pb		1.1×10^{-5}	1.1×10^{-5}
^{214}Pb		1.0×10^{-2}	1.0×10^{-2}
^{210}Bi		1.0×10^{-2}	1.0×10^{-2}

TABLE 10.1-24. Radionuclides Released to the Biosphere from 70-Year Operation of the Integrated Waste Managmenet System for the Once-Through Fuel Cycle Option for Prompt Disposal in Granite Repositories

Radionuclides	8 ISFSFs	3 Repositories	Total
^{3}H	1.4×10^{3}		1.4×10^{3}
^{14}C	2.4		2.4
^{58}Co	1.5×10^{-1}		1.5×10^{-1}
^{60}Co	5.3×10^{-1}		5.3×10^{-1}
^{85}Kr	4.1×10^{5}		4.1×10^{5}
^{90}Sr	9.8×10^{-2}		9.8×10^{-2}
^{91}Y	7.0×10^{-2}		7.0×10^{-2}
^{95}Zr	4.1×10^{-1}		4.1×10^{-1}
^{95}Nb	7.2×10^{-1}		7.2×10^{-1}
^{106}Ru	3.1×10^{-1}		3.1×10^{-1}
^{125m}Te	3.4×10^{-3}		3.4×10^{-3}
^{127m}Te	3.1×10^{-3}		3.1×10^{-3}
^{129}I	2.4×10^{-1}		2.4×10^{-1}
^{134}Cs	4.6		4.6
^{137}Cs	5.5		5.5
^{144}Ce	5.3×10^{-1}		5.3×10^{-1}
^{220}Rn		6.0×10^{1}	6.0×10^{1}
^{222}Rn		5.7×10^{1}	5.7×10^{1}
^{210}Pb		4.8×10^{-3}	4.8×10^{-3}
^{212}Pb		9.0×10^{-2}	9.0×10^{-2}
^{214}Pb		5.7×10^{1}	5.7×10^{1}
^{210}Bi		5.7×10^{1}	5.7×10^{1}

TABLE 10.1-25. Radionuclides Released to the Biosphere from 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Shale Repositories

Radionuclides	8 ISFSFs	6 Repositories	Total
^{3}H	1.4×10^{3}		1.4×10^{3}
^{14}C	2.4		2.4
^{58}Co	1.5×10^{-1}		1.5×10^{-1}
^{60}Co	5.3×10^{-1}		5.3×10^{-1}
^{85}Kr	4.1×10^{5}		4.1×10^{5}
^{90}Sr	9.8×10^{-2}		9.8×10^{-2}
^{91}Y	7.0×10^{-2}		7.0×10^{-2}
^{95}Zr	4.1×10^{-1}		4.1×10^{-1}
^{95}Nb	7.2×10^{-1}		7.2×10^{-1}
^{106}Ru	3.1×10^{-1}		3.1×10^{-1}
^{125m}Te	3.4×10^{-3}		3.4×10^{-3}
^{127m}Te	3.1×10^{-3}		3.1×10^{-3}
^{129}I	2.4×10^{-1}		2.4×10^{-1}
^{134}Cs	4.6		4.6
^{137}Cs	5.5		5.5
^{144}Ce	5.3×10^{-1}		5.3×10^{-1}
^{220}Rn		3.7×10^{1}	3.7×10^{1}
^{222}Rn		4.2×10^{1}	4.2×10^{1}
^{210}Pb		3.5×10^{-2}	3.5×10^{-2}
^{212}Pb		5.5×10^{-2}	5.5×10^{-2}
^{214}Pb		4.2×10^{1}	4.2×10^{1}
^{210}Bi		4.2×10^{1}	4.2×10^{1}

TABLE 10.1-26. Radionuclides Released to the Biosphere from 70-Year Operation of the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Basalt Repositories

Radionuclides	8 ISFSFs	3 Repositories	Total
^{3}H	1.4×10^{3}		1.4×10^{3}
^{14}C	2.4		2.4
^{58}Co	1.5×10^{-1}		1.5×10^{-1}
^{60}Co	5.3×10^{-1}		5.3×10^{-1}
^{85}Kr	4.1×10^{5}		4.1×10^{5}
^{90}Sr	9.8×10^{-2}		9.8×10^{-2}
^{91}Y	7.0×10^{-2}		7.0×10^{-2}
^{95}Zr	4.1×10^{-1}		4.1×10^{-1}
^{95}Nb	7.2×10^{-1}		7.2×10^{-1}
^{106}Ru	3.1×10^{-1}		3.1×10^{-1}
^{125m}Te	3.4×10^{-3}		3.4×10^{-3}
^{127m}Te	3.1×10^{-3}		3.1×10^{-3}
^{129}I	2.4×10^{-1}		2.4×10^{-1}
^{134}Cs	4.6		4.6
^{137}Cs	5.5		5.5
^{144}Ce	5.3×10^{-1}		5.3×10^{-1}
^{220}Rn		9.3	9.3
^{222}Rn		8.1	8.1
^{210}Pb		6.9×10^{-4}	6.9×10^{-4}
^{212}Pb		1.4×10^{-2}	1.4×10^{-2}
^{214}Pb		8.1	8.1
^{210}Bi		8.1	8.1

Radiological Effects

Radiation doses in the vicinity of the waste management facilities for the once-through fuel cycle option during normal operations were calculated based on the radionuclides listed in Tables 10.1-23 through 10.1-26. These doses were based on releases from mining operations; spent fuel storage and packaging operations; and transportation of spent fuel from reactors to storage, packaging, and repository facilities. The only exposure pathway to man and to the environment is via airborne effluents; there will be no planned releases to ground or water. Material normally released from the repositories is naturally occurring radon and its decay products, which are liberated from mined material. Release/dose factors and dose by 5-yr intervals are presented in Appendix D. The 70-year dose commitments from all pathways to the work force, the population within 80 km for all facilities, and the worldwide population are given in Tables 10.1-27 through 10.1-30.

TABLE 10.1-27. 70-Year Total-Body Dose Received from the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Salt Repositories, man-rem

	8 ISFSF	Transportation	8 Repositories	Total	Dose From Naturally Occurring Sources
Regional populations (2 million persons)	1.1×10^1	3.4×10^3	5.4×10^{-2}	3.4×10^3	1×10^7
Worldwide population ($\sim 6 \times 10^9$ persons)	6.1×10^2	0	0	6.1×10^2	$\sim 4 \times 10^{10}$
Work force (occupational or transport)	2.9×10^4	1.4×10^4	4.0×10^4	8.3×10^4	

TABLE 10.1-28. 70-Year Total-Body Dose Received from the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Granite Repositories, man-rem

	8 ISFSF	Transportation	3 Repositories	Total	Dose From Naturally Occurring Sources
Regional populations (2 million persons)	1.1×10^1	3.4×10^3	3.0×10^2	3.7×10^3	1×10^7
Worldwide population ($\sim 6 \times 10^9$ persons)	6.1×10^2	0	0	6.1×10^2	$\sim 4 \times 10^{10}$
Work force (occupational or transport)	2.9×10^4	1.4×10^4	4.0×10^4	8.3×10^4	

TABLE 10.1-29. 70-Year Total-Body Dose Received from the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Shale Repositories, man-rem

	8 ISFSF	Transportation	6 Repositories	Total	Dose From Naturally Occurring Sources
Regional populations (2 million persons)	1.1×10^1	3.4×10^3	2.3×10^2	3.6×10^3	1×10^7
Worldwide population ($\sim 6 \times 10^9$ persons)	6.1×10^2	0	0	6.1×10^2	$\sim 4 \times 10^{10}$
Work force (occupational or transport)	2.9×10^4	1.4×10^4	4.0×10^4	8.3×10^4	

For the doses calculated from routine operations of the once-through facilities, and using values of 100 to 800 health effects per million man-rem, no health effects are expected to occur among the general population.

Ecological Effects

Analysis of ecological effects of operation, both at the process and at the plant level, with one exception, disclosed no potentially serious effects. The exception deals with the large amounts of salt that presumably will be stored on the surface at the geologic repositories

TABLE 10.1-30. 70-Year Total-Body Dose Received from the Integrated Waste Management System for the Once-Through Fuel Cycle Option for Prompt Disposal in Basalt Repositories, man-rem

	8 ISFSF	Transportation	3 Repositories	Total	Dose From Naturally Occurring Sources
Regional populations (2 million persons)	1.1×10^1	3.4×10^3	4.5×10^1	3.4×10^3	1×10^7
Worldwide population ($\sim 6 \times 10^9$ persons)	6.1×10^2	0	0	6.1×10^2	$\sim 4 \times 10^{10}$
Work force (occupational or transport)	2.9×10^4	1.4×10^4	4.0×10^4	8.3×10^4	

in salt. If eight such repositories were constructed, the potential for adverse ecological effects would be eight times those described for the individual repository. It is expected that, having identified the potential deleterious effects of prolonged salt storage, alternative processes will be developed for handling salt tailings from the mines. Commitments to acceptable alternatives have not been made at this writing but will surely be required upon site-specific analyses of ecological impacts. Some similar problems, though on a much reduced scale, would result from shale repositories and to an even lesser extent from repositories in basalt and granite.

The principal ecological effect anticipated from the integrated system is beneficial because of the restriction of human activity on large tracts of land and the resulting enhancement of natural terrestrial productivity. The total amount of land thus available as protected habitat would be between 5600 and 9700 ha (14,000-24,000 acres) for the once-through fuel cycle, depending on the medium for the geologic repository.

Accidents

In previous sections, postulated accidents are described for operation* of each facility. Whatever accident probabilities are postulated for plants or processes can thus be multiplied by the total number of plants or processes to obtain the probability of the accident occurring for the integrated system. The acute environmental consequences to the reference environment would not necessarily be increased by the number of plants because the accident would involve different regional populations for each plant. However, the risk to U.S. society of consequences associated with possible accidents would be increased by the number of plants operating.

* In this context, mining of repositories is classed as construction.

REFERENCES FOR SECTION 10.1

1. Symposium on Cooling Tower Environment, CONF 740302, Energy Research and Development Administration, Washington, DC, pp 353-369, 1974.

2. Air Quality Impacts Due to Construction at LWR Waste Management Facilities, URS Company, URS 7043-01-01, June 1977.

3. Accident Facts, National Safety Council, Chicago, IL, 1974.

10.2 ENVIRONMENTAL EFFECTS ASSOCIATED WITH AN INTEGRATED RADIOACTIVE WASTE MANAGEMENT SYSTEM FOR THE ONCE-THROUGH FUEL CYCLE - DECISION TO DISPOSE OF SPENT FUEL AS WASTE DEFERRED TO YEAR 2000 OR DISPOSAL FACILITIES UNAVAILABLE UNTIL YEAR 2000

10.2 ENVIRONMENTAL EFFECTS ASSOCIATED WITH AN INTEGRATED RADIOACTIVE WASTE MANAGEMENT SYSTEM FOR THE ONCE-THROUGH FUEL CYCLE - DECISION TO DISPOSE OF SPENT FUEL AS WASTE DEFERRED TO YEAR 2000 OR DISPOSAL FACILITIES UNAVAILABLE UNTIL YEAR 2000

If the decision to dispose of spent fuel as waste is deferred until the year 2000 or if disposal repositories are not available until the year 2000, additional storage of spent fuel will be required. The movement of spent fuel in these cases is the same as for prompt disposal through packaging of spent fuel for disposal. At that point the fuel is sent to an extended spent fuel storage facility (ESFSF). The flow of wastes in these cases is shown in Figure 10.2-1.

In addition to all of the facilities described for prompt disposal, the equivalent of three extended spent fuel storage facilities (dry caisson concept) would be required.

Resource commitments for facility construction in the deferred once-through option are presented in Tables 10.2-1 through 10.2-4. Aside from 30-40% increases in requirements for land area and steel, less than a 10% increase in material requirements is required for the deferred option. These additional requirements are believed to have no impact on other industrial uses. Resources required for operation of these plants are insignificant by comparison. The larger of these requirements is the additional 3.2×10^8 kWh of electricity and 1.9×10^3 man-yr of operating labor over the period of 1980-2050.

Addition of three extended spent fuel storage facilities will require about 6.8 million man-hr of construction labor. As a consequence, an additional three construction fatalities and 280 disabling injuries can be expected; this amounts to an addition of less than 5% over those expected from prompt disposal.

During operation of the spent unreprocessed fuel (dry caisson) facility, no planned releases of radioactive material would occur. At the fuel receiving facility (one at each ESFSF), about 1.2×10^{-2} Ci of ^{85}Kr and 70×10^{-8} Ci of ^{129}I would be released to the atmosphere per yr. These releases would add on the order of 1.2×10^{-5} man-rem to the 70-year doses to the regional population if the ESFSFs were colocated. This addition is insignificant when compared with the 1.4×10^7 man-rem to the population from naturally occurring sources.

Environmental impacts associated with routine operation of waste management in deferred or delayed isolation of spent fuel do not appear to be large enough to warrant much weight in the decision to isolate spent fuel promptly or to isolate it beginning in the year 2000.

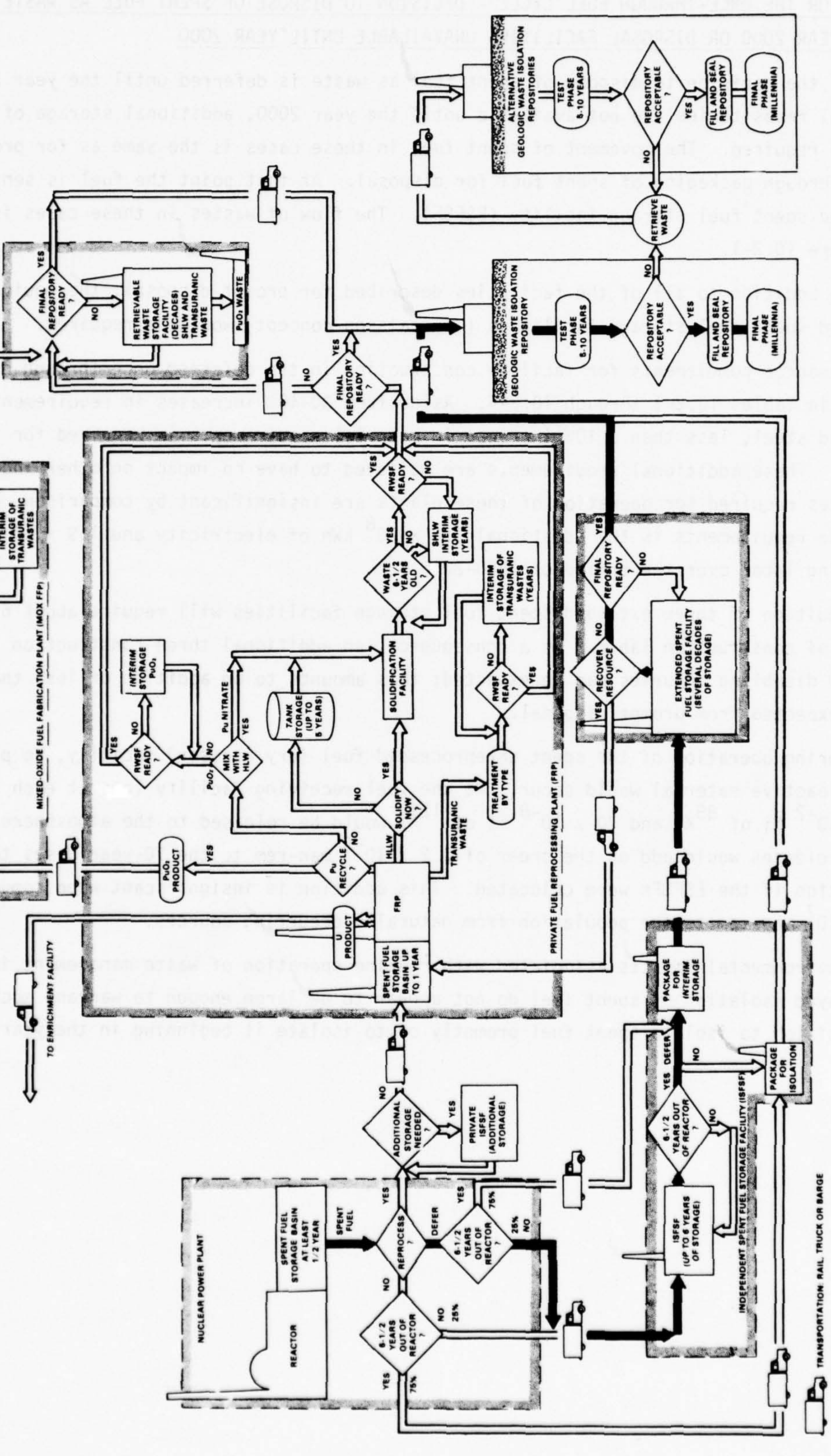

FIGURE 10.2-1. Flow of Spent Fuel and Wastes (Outlined in Black) in the Deferred Isolation Cycle

TABLE 10.2-1. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - for Delayed or Deferred Disposal in Salt Repositories

Resource	8 ISFSFs	3 ESFSFs	Transportation	8 Repositories	Total	Percent Increase Over Prompt Disposal
Water, m^3	8.0×10^5	3.2×10^5		1.9×10^6	3.0×10^6	10
Land, ha						
Surface facilities	8.0×10^1	3.9×10^2		1.4×10^3	1.8×10^3	29
Access roads and railroads	1.1×10^2	4.1×10^1		6.4×10^1	2.2×10^2	29
Mineral and surface rights (fenced restricted area)	3.2×10^3	1.2×10^3		6.5×10^3	1.1×10^4	13
Additional land on which only sub-surface activities will be restricted	--	--		2.6×10^4	2.6×10^4	0
Materials						
Concrete, m^3	3.7×10^5	3.5×10^4		8.0×10^5	1.2×10^6	3
Steel, MT	1.2×10^5	8.0×10^4		1.3×10^5	3.5×10^5	40
Stainless steel, MT	4.9×10^4	--	4.0×10^3	--	5.3×10^4	0
Copper, MT	3.6×10^2	--		1.8×10^3	2.2×10^3	0
Zinc, MT	5.2×10^2	--		4.4×10^2	9.6×10^2	0
Aluminum, MT		--		3.3×10^2	3.3×10^2	0
Lumber, m^3	2.6×10^4	5.7×10^2		1.8×10^4	4.4×10^4	1
Lead, MT		1.9×10^2	6.9×10^3		7.1×10^3	3
Depleted uranium, MT		--	2.8×10^3		2.8×10^3	0
Chromium in stainless steel, MT		--	7.6×10^2		7.6×10^2	0
Nickel in stainless steel, MT		--	4.0×10^2		4.0×10^2	0
Energy						
Propane, m^3	7.6×10^3	2.3×10^3		1.8×10^4	2.8×10^4	8
Diesel fuel, m^3	7.6×10^4	2.4×10^4		1.8×10^5	2.8×10^5	8
Gasoline, m^3	5.1×10^4	1.6×10^4		1.3×10^5	2.0×10^5	11
Electricity						
Total consumption, kWh	3.7×10^7	1.2×10^7		1.1×10^8	1.6×10^8	7
Manpower, man-yr	3.2×10^4	1.0×10^4		8.0×10^4	1.2×10^5	9

TABLE 10.2-2. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - for Delayed or Deferred Disposal in Granite Repositories

Resource	8 ISFSFs	3 ESFSFs	Transportation	3 Repositories	Total	Percent Increase Over Prompt Disposal
Water, m^3	8.0×10^5	3.2×10^5		2.1×10^6	3.2×10^6	10
Land, ha						
Surface facilities	8.0×10^1	3.9×10^2		8.4×10^2	1.3×10^3	41
Access roads and railroads	1.1×10^2	4.1×10^1		2.4×10^1	1.7×10^2	31
Mineral and surface rights (fenced restricted area)	3.2×10^3	1.2×10^3		2.4×10^3	6.8×10^3	21
Additional land on which only subsurface activities will be restricted	--	--		9.6×10^3	9.6×10^3	0
Materials						
Concrete, m^3	3.7×10^5	3.5×10^4		9.0×10^5	1.3×10^6	3
Steel, MT	1.2×10^5	8.0×10^4		1.4×10^5	3.4×10^5	31
Stainless steel, MT	4.9×10^4	--	4.0×10^3	--	5.3×10^4	0
Copper, MT	3.6×10^2	--		2.0×10^3	2.4×10^3	0
Zinc, MT	5.2×10^2	--		4.8×10^2	1.0×10^3	0
Aluminum, MT		--		3.6×10^2	3.6×10^2	0
Lumber, m^3	2.6×10^4	5.7×10^2		2.1×10^4	4.7×10^4	1
Lead, MT		1.9×10^2	6.9×10^3	--	7.1×10^3	3
Depleted uranium, MT		--	2.8×10^3	--	2.8×10^3	0
Chromium in stainless steel, MT		--	7.6×10^2	--	7.6×10^2	0
Nickel in stainless steel, MT		--	4.0×10^2	--	4.0×10^2	0
Energy						
Propane, m^3	7.6×10^3	2.3×10^3		1.9×10^4	2.9×10^4	7
Diesel fuel, m^3	7.6×10^4	2.4×10^4		1.9×10^5	2.9×10^5	7
Gasoline, m^3	5.1×10^4	1.6×10^4		1.4×10^5	2.1×10^5	11
Electricity						
Total consumption, kWh	3.7×10^7	1.2×10^7		1.3×10^8	1.8×10^8	6
Manpower, man-yr	3.2×10^4	1.0×10^4		9.0×10^4	1.3×10^5	8

TABLE 10.2-3. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - for Delayed or Deferred Disposal in Shale Repositories

Resource	8 ISFSFs	3 ESFSFs	Transportation	6 Repositories	Total	Percent Increase Over Prompt Disposal
Water, m^3	8.0×10^5	3.2×10^5		2.2×10^6	3.3×10^6	10
Land, ha						
Surface facilities	8.0×10^1	3.9×10^2		1.1×10^3	1.6×10^3	45
Access roads and railroads	1.1×10^2	4.1×10^1		4.8×10^1	2.0×10^2	25
Mineral and surface rights (fenced restricted area)	3.2×10^3	1.2×10^3		4.9×10^3	9.3×10^3	15
Additional land on which only subsurface activities will be restricted	--	--		1.9×10^4	1.9×10^4	0
Materials						
Concrete, m^3	3.7×10^5	3.5×10^4		9.0×10^5	1.3×10^6	3
Steel, MT	1.2×10^5	8.0×10^4		1.4×10^5	3.4×10^5	31
Stainless steel, MT	4.9×10^4	--	4.0×10^3	--	5.3×10^4	0
Copper, MT	3.6×10^2	--		2.0×10^3	2.4×10^3	0
Zinc, MT	5.2×10^2	--		4.8×10^2	1.0×10^3	0
Aluminum, MT		--		3.8×10^2	3.8×10^2	0
Lumber, m^3	2.6×10^4	5.7×10^2		1.8×10^4	4.4×10^4	1
Lead, MT		1.9×10^2	6.9×10^3	--	7.1×10^2	3
Depleted uranium, MT		--	2.8×10^3	--	2.8×10^3	0
Chromium in stainless steel, MT		--	7.6×10^2	--	7.6×10^2	0
Nickel in stainless steel, MT		--	4.0×10^2	--	4.0×10^2	0
Energy						
Propane, m^3	7.6×10^3	2.3×10^3		1.9×10^4	2.9×10^4	7
Diesel fuel, m^3	7.6×10^4	2.4×10^4		1.9×10^5	2.9×10^5	7
Gasoline, m^3	5.1×10^4	1.6×10^4		1.3×10^5	2.0×10^5	11
Electricity						
Total consumption, kWh	3.7×10^7	1.2×10^7		1.3×10^8	1.8×10^8	6
Manpower, man-yr	3.2×10^4	1.0×10^4		8.4×10^4	1.3×10^5	8

TABLE 10.2-4. Resource Commitments for Construction of the Integrated Waste Management System for the Once-Through Fuel Cycle Option, 1980-2050 - for Delayed or Deferred Disposal in Basalt Repositories

Resource	8 ISFSFs	3 ESFSFs	Transportation	3 Repositories	Total	Percent Increase Over Prompt Disposal
Water, m^3	8.0×10^5	3.2×10^5		1.8×10^6	2.9×10^6	10
Land, ha						
Surface facilities	8.0×10^1	3.9×10^2		8.4×10^2	1.3×10^3	41
Access roads and railroads	1.1×10^2	4.1×10^1		2.4×10^1	1.8×10^2	38
Mineral and surface rights (fenced restricted area)	3.2×10^3	1.2×10^3		2.4×10^3	6.8×10^3	21
Additional land on which only subsurface activities will be restricted	--	--		9.6×10^3	9.6×10^3	0
Materials						
Concrete, m^3	3.7×10^5	3.5×10^4		7.5×10^5	1.2×10^6	9
Steel, MT	1.2×10^5	8.0×10^4		1.2×10^5	3.2×10^5	33
Stainless steel, MT	4.9×10^4	--	4.0×10^3	--	5.3×10^4	0
Copper, MT	3.6×10^2	--		1.7×10^3	2.1×10^3	0
Zinc, MT	5.2×10^2	--		4.2×10^2	9.4×10^2	0
Aluminum, MT		--		3.3×10^2	3.3×10^2	0
Lumber, m^3	2.6×10^4	5.7×10^2		1.8×10^4	4.4×10^4	1
Lead, MT		1.9×10^2	6.9×10^3	--	7.1×10^3	3
Depleted uranium, MT		--	2.8×10^3	--	2.8×10^3	0
Chromium in stainless steel, MT		--	7.6×10^2	--	7.6×10^2	0
Nickel in stainless steel, MT		--	4.0×10^2	--	4.0×10^2	0
Energy						
Propane, m^3	7.6×10^3	2.3×10^3		1.6×10^4	2.6×10^4	8
Diesel fuel, m^3	7.6×10^4	2.4×10^4		1.6×10^5	2.6×10^5	8
Gasoline, m^3	5.1×10^4	1.6×10^4		1.2×10^5	1.9×10^5	12
Electricity						
Total consumption, kWh	3.7×10^7	1.2×10^7		1.1×10^8	1.6×10^8	7
Manpower, man-yr	3.2×10^4	1.0×10^4		1.1×10^5	1.5×10^5	7

10.3 ENVIRONMENTAL EFFECTS ASSOCIATED WITH AN INTEGRATED RADIOACTIVE WASTE MANAGEMENT SYSTEM FOR LWR FUEL REPROCESSING FOR URANIUM AND PLUTONIUM RECYCLE WITH PROMPT DISPOSAL OF TRANSURANIC WASTES

10.3 ENVIRONMENTAL EFFECTS ASSOCIATED WITH AN INTEGRATED RADIOACTIVE WASTE MANAGEMENT SYSTEM FOR LWR FUEL REPROCESSING FOR URANIUM AND PLUTONIUM RECYCLE WITH PROMPT DISPOSAL OF TRANSURANIC WASTES

In the reference system, LWR fuel reprocessing can lead to three fuel cycle options: 1) uranium and plutonium recycle, 2) uranium recycle with plutonium in solidified high-level waste, and 3) uranium recycle with plutonium separated, converted to the oxide, and stored at a federal retrievable waste storage facility. The reprocessing and waste management steps are essentially the same for all three options, differing principally in the handling of the plutonium. Because of this similarity, the environmental impacts associated with the uranium and plutonium recycle option are discussed in detail, while only the major differences in environmental effects are noted for the other two options. Details of some aspects of the uranium-only recycle option are presented in Section 10.6.

Plants and/or functions for which environmental impacts of radioactive wastes management are considered in the uranium and plutonium recycle mode are:

- treatment of radioactive gaseous effluents at the FRP
- onplant interim storage of solidified high-level wastes, transuranic wastes, and ^{85}Kr
- transport of solidified high-level wastes and transuranic wastes to a geologic repository
- treatment of gaseous effluents at the MOX FFP
- onplant storage of transuranic wastes
- truck transport of MOX FFP transuranic wastes to a geologic repository.

In the uranium and plutonium recycle option, spent fuel from LWRs will be moved into reactor spent fuel storage basins for at least one-half year. From there it will be transferred to the receiving basin at the fuel reprocessing plant (FRP), where it will remain until it has been out of the reactor 1-1/2 years before reprocessing. At the FRP the fuel will be dissolved and the uranium and plutonium separated out; the uranium will be sent to an enrichment plant and the plutonium to a mixed-oxide fuel fabrication plant (MOX FFP).

In the reference system, high-level waste from the FRP will be solidified by vitrification, following calcination, and stored until the time out of the reactor reaches 6-1/2 years, at which time it will be sent to a deep geologic (salt) repository. Fuel residues and non-high-level transuranic wastes from the FRP will also be sent to the deep geologic repository. Non-high-level transuranic wastes result from failed equipment, noncombustible trash, and wet wastes and incinerator ash that have been immobilized in cement. Krypton that has been removed from dissolver off gas will be stored onsite at the FRP. All wastes generated at the MOX FFP will be assumed to be contaminated with transuranic radionuclides. After packaging, incineration, or immobilization (as appropriate for the waste form) the wastes will be sent to the salt repository for isolation. Waste flow in the uranium and plutonium recycle option is shown in Figure 10.3-1.

During the reference LWR period (1980 to 2050), six 2000-MTHM/yr FRPs and one 1500-MTHM/yr FRP, ten MOX FFPs, and six geologic waste repositories in salt will be built and operated.

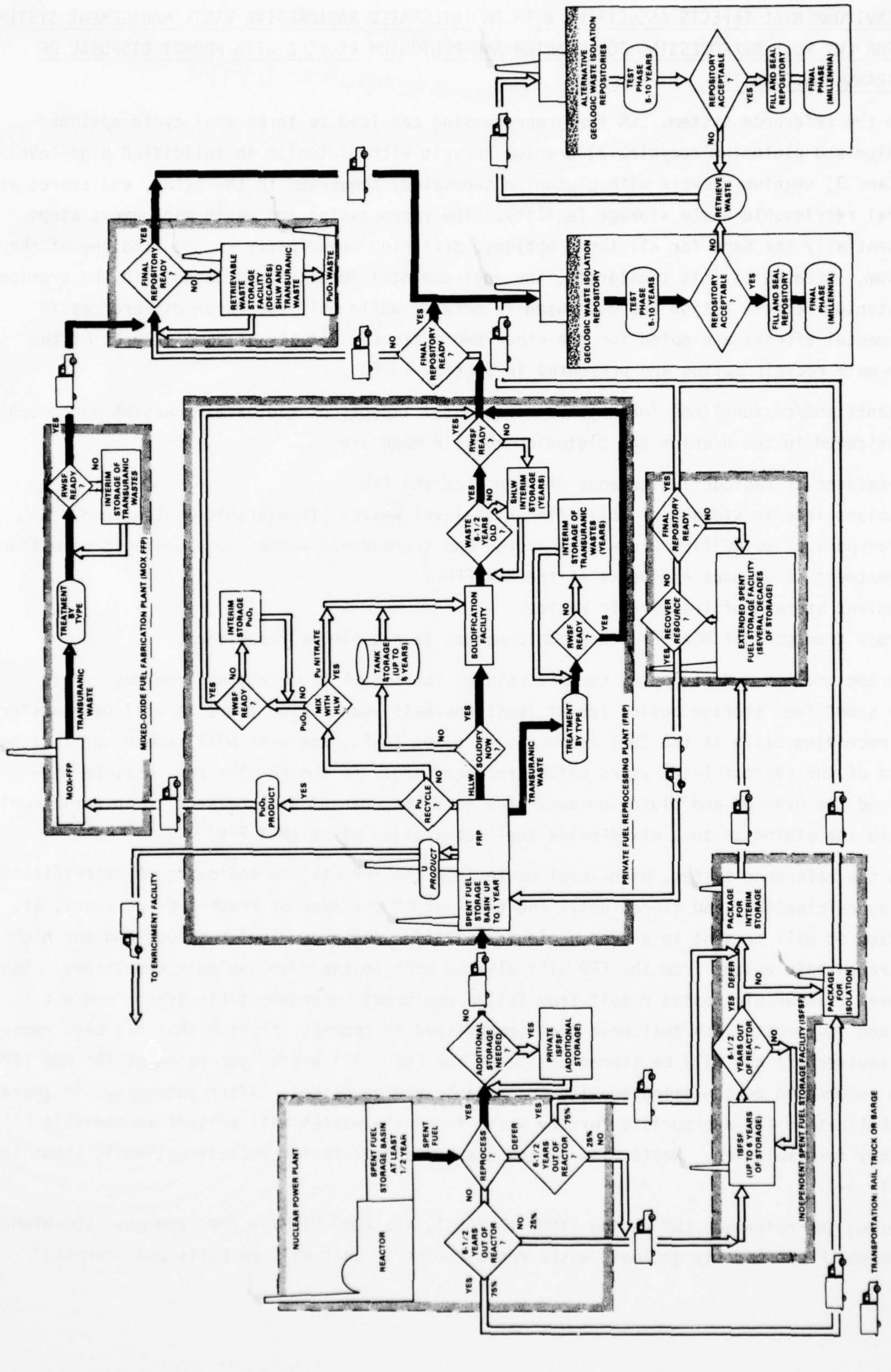

FIGURE 10.3-1. Flow of Spent Fuel and Wastes (Outlined in Black) in the Uranium and Plutonium Recycle Option

Solidified high-level waste and fuel residues will be transported from the FRP to the repository by rail. Trucks will be used to transport non-high-level transuranic wastes from the FRP and MOX FFP to the repository. Waste plutonium oxide in the uranium recycle option will be shipped by rail to the repository if it is disposed of in solidified high-level waste, or will be shipped by truck to a retrievable waste storage facility on the surface if it is to be stored. The environmental effects of construction and operation of this integrated system of plants and of the transportation of the waste is summarized in the following sections.

10.3.1 Environmental Effects Related to Construction of the Integrated Waste Management System

During construction of the FRPs and MOX FFPs, waste management facilities will be built at the plant sites. Surface facilities for the repositories will be constructed along with mining of the main shaft and construction of storage rooms, which are necessary prior to waste emplacement at the repositories. Casks for waste transportation will also be constructed.

Resource Commitments

Land will be required for all surface facilities and for underground mine storage at the repositories. Construction activities, roads, and railroads for access to the sites will also require land. Additional land will be required to limit access to the facilities for security reasons.

In terms of land use, about 4900 ha will be needed for waste management facilities. This represents about 30% of the total land ($\sim$17,000 ha) required for fuel reprocessing facilities. Of the land commitment for waste management, approximately all of the 4900 ha is required fo. deep geologic repositories. Structures and access roads for the combined production and waste management facilities will occupy about 500 ha. The remaining land will be restricted from human activities and should provide protected habitat for biota. Since withdrawal of land from present use is highly site specific in terms of impact on agriculture or other uses, no further analysis of land use is made in this generic statement.

Water use is also highly site specific in terms of potential environmental impact. As long as water is supplied from sources such as the R River in the reference environment, no significant effects, either on aquatic biota or other downstream uses, would be expected. In the event that plants are built as described, site-specific evaluations will be required. However, because there are no unusually high demands for water for construction of individual facilities, siting for purposes of water use will probably not be a problem.

Resources committed in the construction of fuel reprocessing waste management facilities are presented in Tables 10.3-1 through 10.3-4. For comparison, the tables also show resource commitments for the fuel reprocessing production facilities. For many of the resources listed in Tables 10.3-1 through 10.3-4, waste management activities require greater quantities of resources than do the production facilities. However, since this construction program will span about 50 years, these resource commitments are not expected to significantly impact other industrial needs.

No unusual transportation requirements have been identified for construction of the facilities.

TABLE 10.3-1. Resource Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Prompt Disposal in Salt Repositories

Resource	6.75 FRPs(a)	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	6 Repositories	Transportation	Total For(b) Production Facilities	Total For(c) Waste Management
Land, ha								
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	1.1×10^3		3.3×10^2	1.2×10^3
Access roads and railroads	3.3×10^2	--	1.2×10^2	--	4.8×10^1		4.5×10^2	4.8×10^1
Mineral and surface rights (property)	1.6×10^4	--	4.0×10^3	--	4.9×10^3		2.0×10^4	4.9×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	1.6×10^6		1.7×10^6	2.6×10^6
Materials								
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	6.6×10^5		9.2×10^5	1.2×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.1×10^5	2.3×10^3	2.3×10^5	2.4×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	1.4×10^3		1.5×10^3	2.9×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1		3.7×10^2		1.5×10^2	1.1×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		2.8×10^2		1.5×10^3	3.1×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	1.6×10^4		3.9×10^4	5.2×10^4
Lead, MT		4.4×10^2				5.2×10^3		5.6×10^3
Chromium, MT (in SS)						4.1×10^2		4.1×10^2
Nickel, MT (in SS)						1.8×10^2		1.8×10^2
Energy								
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	1.4×10^4		1.4×10^4	2.3×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	1.4×10^5		9.6×10^4	2.2×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	1.1×10^5		9.6×10^4	1.7×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	9.6×10^7		8.2×10^7	1.4×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	6.6×10^4		6.4×10^4	1.1×10^5

a. Six 2,000-MTHM/yr capacity FRPs and one 1,500-MTHM/yr capacity FRP.
b. Includes 6.75 FRPs and 10 MOX FFPs.
c. Includes waste management at FRPs and MOX FFPs, repositories, and transportation.

TABLE 10.3-2. Resource Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Prompt Disposal in Granite Repositories

Resource	6.75 FRPs(a)	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	7 Repositories	Transportation	Total For(b) Production Facilities	Total For(c) Waste Management
Land, ha								
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	1.5×10^3		3.3×10^2	1.6×10^3
Access roads and railroads	3.3×10^2	--	1.2×10^2	--	5.6×10^1		4.5×10^2	5.6×10^1
Mineral and surface rights (property)	1.6×10^4	--	4.0×10^3	--	5.7×10^3		2.0×10^4	5.7×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	3.6×10^6		1.7×10^6	4.6×10^6
Materials								
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	1.5×10^6		9.2×10^5	2.1×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	2.3×10^5	2.3×10^3	2.3×10^5	3.6×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	3.3×10^3		1.5×10^3	4.8×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1		8.4×10^2		1.5×10^2	1.6×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		6.3×10^2		1.5×10^3	6.6×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	3.4×10^4		3.9×10^4	7.0×10^4
Lead, MT		4.4×10^2				5.2×10^3		5.6×10^3
Chromium, MT (in SS)						4.1×10^2		4.1×10^2
Nickel, MT (in SS)						1.8×10^2		1.8×10^2
Energy								
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	3.2×10^4		1.4×10^4	4.1×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	3.2×10^5		9.6×10^4	4.0×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	2.3×10^5		9.6×10^4	2.9×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	2.1×10^8		8.2×10^7	2.6×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.5×10^5		6.4×10^4	1.9×10^5

a. Six 2,000-MTHM/yr capacity FRPs and one 1,500-MTHM/yr capacity FRP.
b. Includes 6.75 FRPs and 10 MOX FFPs.
c. Includes waste management at FRPs and MOX FFPs, repositories, and transportation.

TABLE 10.3-3. Resource Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Prompt Disposal in Shale Repositories

Resource	6.75 FRPs(a)	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	10 Repositories	Transportation	Total For(b) Production Facilities	Total For(c) Waste Management
Land, ha								
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	1.8×10^3		3.3×10^2	1.9×10^3
Access roads and railroads	3.3×10^2	--	1.2×10^2	--	8.0×10^1		4.5×10^2	8.0×10^1
Mineral and surface rights (property)	1.6×10^4	--	4.0×10^3	--	8.1×10^3		2.0×10^4	8.1×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	2.9×10^6		1.7×10^6	3.9×10^6
Materials								
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	1.2×10^6		9.2×10^5	1.8×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.9×10^5	2.3×10^3	2.4×10^5	3.2×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	2.6×10^3		1.5×10^3	4.1×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1		6.7×10^2		1.5×10^2	1.4×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		5.0×10^2		1.5×10^3	5.3×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	2.8×10^7		3.9×10^4	6.4×10^4
Lead, MT		4.4×10^2				5.2×10^3		5.6×10^3
Chromium, MT (in SS)						4.1×10^2		4.1×10^2
Nickel, MT (in SS)						1.8×10^2		1.8×10^2
Energy								
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	2.6×10^4		1.4×10^4	3.5×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	2.6×10^5		9.6×10^4	3.4×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	1.9×10^5		9.6×10^4	2.5×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	1.7×10^8		8.2×10^7	2.2×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.3×10^5		6.4×10^4	1.7×10^5

a. Six 2,000-MTHM/yr capacity FRPs and one 1,500-MTHM/yr capacity FRP.
b. Includes 6.75 FRPs and 10 MOX FFPs.
c. Includes waste management at FRPs and MOX FFPs, repositories, and transportation.

TABLE 10.3-4. Resource Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Prompt Disposal in Basalt Repositories

Resource	6.75 FRPs(a)	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	6 Repositories	Transportation	Total For(b) Production Facilities	Total For(c) Waste Management
Land, ha								
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	1.3×10^3		3.3×10^2	1.4×10^3
Access roads and railroads	3.3×10^2	--	1.2×10^2	--	4.8×10^1		4.5×10^2	4.8×10^1
Mineral and surface rights (property)	1.6×10^4	--	4.0×10^3	--	4.9×10^3		2.0×10^4	4.9×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	2.7×10^6		1.7×10^6	3.7×10^6
Materials								
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	1.1×10^6		9.2×10^5	1.7×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.8×10^5	2.3×10^3	2.4×10^5	3.1×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	2.5×10^3		1.5×10^3	4.0×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1		6.6×10^2		1.5×10^2	1.4×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		4.6×10^2		1.5×10^3	4.9×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	2.6×10^4		3.9×10^4	6.2×10^4
Lead, MT		4.4×10^2				5.2×10^3		5.6×10^3
Chromium, MT (in SS)						4.1×10^2		4.1×10^2
Nickel, MT (in SS)						1.8×10^2		1.8×10^2
Energy								
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	2.4×10^4		1.4×10^4	3.3×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	2.4×10^5		9.6×10^4	3.3×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	1.6×10^5		9.6×10^4	2.2×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	1.6×10^8		8.2×10^7	2.1×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.6×10^5		6.4×10^4	2.0×10^5

a. Six 2,000 MTHM/yr capacity FRPs and one 1,500-MTHM/yr capacity FRP.
b. Includes 6.75 FRPs and 10 MOX FFPs.
c. Includes waste management at FRPs and MOX FFPs, repositories, and transportation.

Nonradiological Effluents

Effluents from construction of the waste management facilities will include dust generated from construction of surface facilities and from rocks (salt, granite, shale, and basalt) brought to the surface during repository mining, and pollutants from operation of machinery. Dust from mining and transport within the mine is removed by filters in the mine ventilation system; surface handling and transport of mined materials is expected to result in the greatest dust generation. Maximum dust emissions per day from surface handling of mined materials are presented in Table 10.3-5 for the four geologic media.

TABLE 10.3-5. Maximum Dust Emissions From Surface Handling of Mined Material, MT/d

	Repository Medium			
Climate	Salt	Granite	Shale	Basalt
Reference	3.6	5.6	3.1	6.1
Arid	49	79	44	86

The maximum and average concentrations of dust resulting from surface storage were calculated at the fenceline (1.6 km) for one repository. The concentrations are presented in Table 10.3-6 for the four geologic media.

TABLE 10.3-6. Dust Concentrations at Repository Fenceline, $\mu g/m^3$

Repository Medium	Maximum	Average
Salt		
Reference	130	71
Arid	1600	930
Granite		
Reference	200	120
Arid	2400	1400
Shale		
Reference	110	66
Arid	1400	790
Basalt		
Reference	210	130
Arid	2600	1600

The primary federal air quality standard for suspended particulate matter computed as an annual geometric mean is 75 $\mu g/m^3$. Thus, for both the reference site and any proposed arid site, there would be a degradation of air quality without application of appropriate control techniques during surface handling of mined material.

Surface storage of salt would be of major concern because of its toxic properties. However, containment of salt will require thorough analysis if and when site-specific projects are developed. It is possible that if salt brought to the surface is not properly managed, the result could be the most serious environmental impact associated with the waste repository. Covering the salt piles with asphalt paving has been suggested to preclude dispersal of salt dust in arid climates. It would also be possible to remove the salt stored on the surface and dispose of it by use in industry, placement in other mines, dispersion at sea, etc. Managing the salt is not an insurmountable problem and probably has several practical solutions.

Tables 10.3-7 through 10.3-10 list the pollutants released to the atmosphere from operation of machinery on the surface and in the mines during construction of the integrated system facilities for the uranium and plutonium recycle option. Concentrations of pollutants in air at facility fencelines from these emissions are not expected to result in air quality effects outside of regulatory limits. Quantities in Tables 10.3-7 through 10.3-10 were developed from the total quantities of fuel burned and emission factors for a given effluent.[1]

TABLE 10.3-7. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Salt Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	6 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	5.3×10^4	9.1×10^4
Hydrocarbons, MT	3.4×10^3	2.5×10^2	2.4×10^3	6.1×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	1.0×10^4	1.4×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	6.0×10^2	8.2×10^2
Particulates, MT	5.7×10^3	1.5×10^3	6.0×10^2	7.8×10^3

TABLE 10.3-8. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Granite Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	7 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	1.1×10^5	1.5×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	5.2×10^3	8.9×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	2.2×10^4	2.6×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	1.3×10^3	1.5×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.3×10^3	8.5×10^3

Ecological Effects

Ecological effects associated with construction would be expected to be substantially the same as those discussed in Section 10.1 for the once-through cycle.

TABLE 10.3-9. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Shale Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	10 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	9.3×10^4	1.3×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	4.2×10^3	7.9×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	1.8×10^4	2.2×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	1.1×10^3	1.3×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.1×10^3	8.3×10^3

TABLE 10.3-10. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Basalt Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	6 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	9.0×10^4	1.3×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	4.0×10^3	7.7×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	1.7×10^4	2.1×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	1.0×10^3	1.2×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.0×10^3	8.2×10^3

Accidents

Injuries and fatalities forecasted for construction of waste management facilities through the year 2050 are presented in Tables 10.3-11 through 10.3-14.

TABLE 10.3-11. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option Through 2050 with Prompt Disposal in Salt Repositories

	6.75 FRPs	10 MOX FFPs	Transportation[a]	6 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	3.0×10^3	4.7×10^3
Fatalities	1.4×10^1	1.0	5.2×10^1	6.0×10^1	1.3×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

Injury rates of 13.6 disabling injuries per million man-hr for surface construction and 25 disabling injuries per million man-hr for underground mining were used. For fatality predictions, fatality rates of 0.17 fatalities per million man-hr[2] for surface construction and 0.53 fatalities per million man-hr for underground mining were used.

TABLE 10.3-12. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option Through 2050 with Prompt Disposal in Granite Repositories

	6.75 FRPs	10 MOX FFPs	Transportation[a]	7 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	7.7×10^3	9.4×10^3
Fatalities	1.4×10^1	1.0	5.2×10^1	1.5×10^2	2.2×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

TABLE 10.3-13. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option Through 2050 with Prompt Disposal in Shale Repositories

	6.75 FRPs	10 MOX FFPs	Transportation[a]	10 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	5.9×10^3	7.6×10^3
Fatalities	1.4×10^1	1.0	5.2×10^1	1.2×10^2	1.9×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

TABLE 10.3-14. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option Through 2050 with Prompt Disposal in Basalt Repositories

	6.75 FRPs	10 MOX FFPs	Transportation[a]	6 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	7.8×10^3	9.5×10^3
Fatalities	1.4×10^1	1.0	5.2×10^1	1.6×10^2	2.3×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

Depending on the geologic medium, 55-75% of the disabling injuries for the integrated system are due to underground mining. For fatalities, 40-65% are due to underground mining at the repositories.

10.3.2 Environmental Effects Related to Operation of the Integrated Waste Management System

During operation of the spent fuel reprocessing facilities, radioactive wastes generated at the FRPs and MOX FFPs will be treated, stored onsite for up to 5 years, and transported to deep geologic repositories for final isolation. Each plant will operate for 30 years and then be decommissioned. The deep geologic repositories will receive wastes for about 8 to 20 years, depending on the rate of waste generation.

Resource Commitments

Materials and energy requirements during operation (1980 to 2050) of the waste management facilities associated with uranium and plutonium recycle are given in Tables 10.3-15 through 10.3-18.

TABLE 10.3-15. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option With Prompt Disposal in Salt Repositories

Resource	6.75 FRPs	10 MOX FFPs	Transportation	6 Repositories	Total
Materials					
Steel, MT					
HLW canister overpacks				3.8×10^1	3.8×10^1
ILW drumpacks				3.2×10^5	3.2×10^5
FRW/ILW canister overpacks				9.0×10^1	9.0×10^1
HLW retrievability sleeves				4.4×10^3	4.4×10^3
FRW/ILW retrievability sleeves				1.7×10^5	1.7×10^5/ 4.9×10^5
Concrete, MT				4.4×10^5	4.4×10^5
Lime, MT		1.9×10^3			1.9×10^3
Acetylene	1.0×10^2	1.5×10^1			1.2×10^2
Stainless steel, MT	4.5×10^4				4.5×10^4
CaO, MT	2.8×10^2				2.8×10^2
Gas cylinders	3.0×10^4				3.0×10^4
Frit, MT	5.1×10^4				5.1×10^4
Sand, MT	1.3×10^5				1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5			3.3×10^5
Caustic, m^3	1.6×10^3				1.6×10^3
HNO_3, m^3	2.4×10^3				2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3			1.1×10^4
NH_3, MT	2.8×10^4				2.8×10^4
Argon, m^3	1.8×10^6				1.8×10^6
Helium, m^3	1.4×10^5				1.4×10^5
Liquid nitrogen, m^3	8.1×10^4				8.1×10^4
Silver zeolite, m^3	4.3×10^3				4.3×10^3
Silica gel, m^3	1.0×10^2				1.0×10^2
Detergent, MT	1.1×10^2				1.1×10^2
55-gal drums	1.2×10^6				1.2×10^6
Waste canisters					
0.76 x 3.05 m	9.7×10^4				9.7×10^4
0.3 x 3 m	1.3×10^5				1.3×10^5
Cardboard boxes (30 x 30 x 60 cm)	2.0×10^6	1.4×10^5			2.1×10^6
Plastic sheets, m^2	1.3×10^5				1.3×10^5
Filters	6.5×10^4				6.5×10^4
Plywood, m^2	6.9×10^5				6.9×10^5
Utilities					
Water consumed, m^3	8.9×10^7	2.5×10^5		--	8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.3×10^{10}	3.1×10^{10}
Steam, MT	--	--		9.0×10^7	9.0×10^7
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	1.5×10^6	2.8×10^6
Propane, m^3	2.0×10^7	3.0×10^6		--	2.3×10^7
Oil, m^3	7.7×10^4	--		--	7.7×10^4
Coal, MT	--	--		8.4×10^6	8.4×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		1.1×10^5	1.4×10^5

TABLE 10.3-16. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Prompt Disposal in Granite Repositories

Resource	6.75 FRPs	10 MOX FFPs	Transportation	7 Repositories	Total
Materials					
Steel, MT					
HLW canister overpacks				5.7×10^1	5.7×10^1
ILW drumpacks				4.1×10^5	4.1×10^5
FRW/ILW canister overpacks				1.1×10^2	1.1×10^2
HLW retrievability sleeves				6.7×10^3	6.7×10^3
FRW/ILW retrievability sleeves				1.3×10^6	1.3×10^6/ 1.7×10^6
Concrete, MT				5.1×10^5	5.1×10^5
Lime, MT		1.9×10^3			1.9×10^3
Acetylene	1.0×10^2	1.5×10^1			1.2×10^2
Stainless steel, MT	4.5×10^4				4.5×10^4
CaO, MT	2.8×10^2				2.8×10^2
Gas cylinders	3.0×10^4				3.0×10^4
Frit, MT	5.1×10^4				5.1×10^4
Sand, MT	1.3×10^5				1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5			3.3×10^5
Caustic, m^3	1.6×10^3				1.6×10^3
HNO_3, m^3	2.4×10^3				2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3			1.1×10^4
NH_3, MT	2.8×10^4				2.8×10^4
Argon, m^3	1.8×10^6				1.8×10^6
Helium, m^3	1.4×10^5				1.4×10^5
Liquid nitrogen, m^3	8.1×10^4				8.1×10^4
Silver zeolite, m^3	4.3×10^3				4.3×10^3
Silica gel, m^3	1.0×10^2				1.0×10^2
Detergent, MT	1.1×10^2				1.1×10^2
55-gal drums	1.2×10^6				1.2×10^6
Waste canisters					
0.76 x 3.05 m	9.7×10^4				9.7×10^4
0.3 x 3 m	1.3×10^5				1.3×10^5
Cardboard boxes (30 x 30 x 60 cm)	2.0×10^6	1.4×10^5			2.1×10^6
Plastic sheets, m^2	1.3×10^5				1.3×10^5
Filters	6.5×10^4				6.5×10^4
Plywood, m^2	6.9×10^5				6.9×10^5
Utilities					
Water consumed, m^3	8.9×10^7	2.5×10^5		--	8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.8×10^{10}	3.6×10^{10}
Steam, MT	--	--		1.1×10^8	1.1×10^8
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	1.8×10^6	3.1×10^6
Propane, m^3	2.0×10^7	3.0×10^6		--	2.3×10^7
Oil, m^3	7.7×10^4	--		--	7.7×10^4
Coal, MT	--	--		9.8×10^6	9.8×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		1.7×10^5	2.0×10^5

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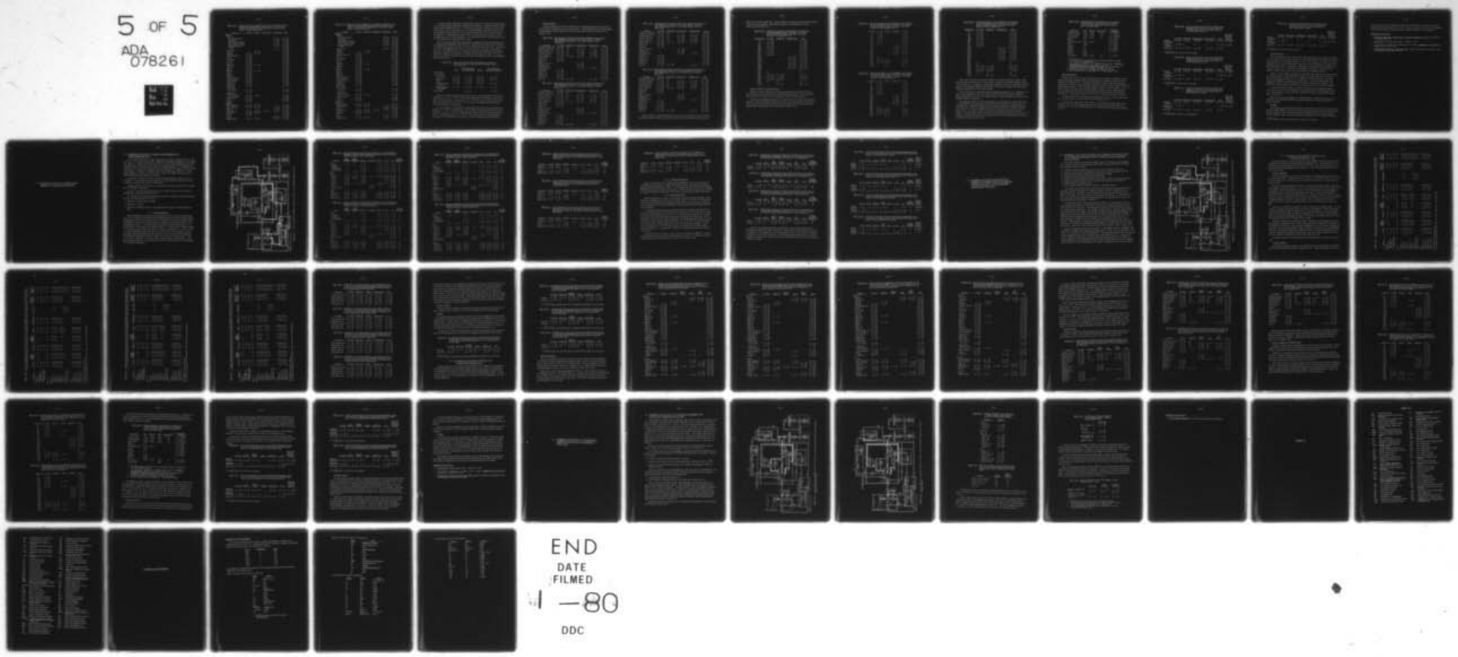

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TABLE 10.3-17. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Prompt Disposal in Shale Repositories

Resource	6.75 FRPs	10 MOX FFPs	Transportation	10 Repositories	Total
Materials					
Steel, MT					
HLW canister overpacks				4.8×10^1	4.8×10^1
ILW drumpacks				3.0×10^5	3.0×10^5
FRW/ILW canister overpacks				1.0×10^2	1.0×10^2
HLW retrievability sleeves				1.3×10^4	1.3×10^4
FRW/ILW retrievability sleeves				2.9×10^5	2.9×10^5/ 6.0×10^5
Concrete, MT				7.3×10^5	7.3×10^5
Lime, MT		1.9×10^3			1.9×10^3
Acetylene	1.0×10^2	1.5×10^1			1.2×10^2
Stainless steel, MT	4.5×10^4				4.5×10^4
CaO, MT	2.8×10^2				2.8×10^2
Gas cylinders	3.0×10^4				3.0×10^4
Frit, MT	5.1×10^4				5.1×10^4
Sand, MT	1.3×10^5				1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5			3.3×10^5
Caustic, m^3	1.6×10^3				1.6×10^3
HNO_3, m^3	2.4×10^3				2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3			1.1×10^4
NH_3, MT	2.8×10^4				2.8×10^4
Argon, m^3	1.8×10^6				1.8×10^6
Helium, m^3	1.4×10^5				1.4×10^5
Liquid nitrogen, m^3	8.1×10^4				8.1×10^4
Silver zeolite, m^3	4.3×10^3				4.3×10^3
Silica gel, m^3	1.0×10^2				1.0×10^2
Detergent, MT	1.1×10^2				1.1×10^2
55-gal drums	1.2×10^6				1.2×10^6
Waste canisters					
0.76 x 3.05 m	9.7×10^4				9.7×10^4
0.3 x 3 m	1.3×10^5				1.3×10^5
Cardboard boxes (30 x 30 x 60 cm)	2.0×10^6	1.4×10^5			2.1×10^6
Plastic sheets, m^2	1.3×10^5				1.3×10^5
Filters	6.5×10^4				6.5×10^4
Plywood, m^2	6.9×10^5				6.9×10^5
Utilities					
Water consumed, m^3	8.9×10^7	2.5×10^5		--	8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.4×10^{10}	3.2×10^{10}
Steam, MT	--	--		1.0×10^8	1.0×10^8
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	1.7×10^6	3.0×10^6
Propane, m^3	2.0×10^7	3.0×10^6		--	2.3×10^7
Oil, m^3	7.7×10^4	--		--	7.7×10^4
Coal, MT	--	--		9.4×10^6	9.4×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		1.3×10^5	1.6×10^5

TABLE 10.3-18. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Prompt Disposal in Basalt Repositories

Resource	6.75 FRPs	10 MOX FFPs	Transportation	6 Repositories	Total
Materials					
Steel, MT					
HLW canister overpacks				5.4×10^{1}	5.4×10^{1}
ILW drumpacks				2.9×10^{5}	2.9×10^{5}
FRW/ILW canister overpacks				8.4×10^{1}	8.4×10^{1}
HLW retrievability sleeves				7.8×10^{3}	7.8×10^{3}
FRW/ILW retrievability sleeves				9.6×10^{5}	9.6×10^{5}/ 1.3×10^{6}
Concrete, MT				4.4×10^{5}	4.4×10^{5}
Lime, MT		1.9×10^{3}			1.9×10^{3}
Acetylene	1.0×10^{2}	1.5×10^{1}			1.2×10^{2}
Stainless steel, MT	4.5×10^{4}				4.5×10^{4}
CaO, MT	2.8×10^{2}				2.8×10^{2}
Gas cylinders	3.0×10^{4}				3.0×10^{4}
Frit, MT	5.1×10^{4}				5.1×10^{4}
Sand, MT	1.3×10^{5}				1.3×10^{5}
Cement, MT	2.2×10^{5}	1.1×10^{5}			3.3×10^{5}
Caustic, m^3	1.6×10^{3}				1.6×10^{3}
HNO_3, m^3	2.4×10^{3}				2.4×10^{3}
NaOH, MT	1.0×10^{4}	1.1×10^{3}			1.1×10^{4}
NH_3, MT	2.8×10^{4}				2.8×10^{4}
Argon, m^3	1.8×10^{6}				1.8×10^{6}
Helium, m^3	1.4×10^{5}				1.4×10^{5}
Liquid nitrogen, m^3	8.1×10^{4}				8.1×10^{4}
Silver zeolite, m^3	4.3×10^{3}				4.3×10^{3}
Silica gel, m^3	1.0×10^{2}				1.0×10^{2}
Detergent, MT	1.1×10^{2}				1.1×10^{2}
55-gal drums	1.2×10^{6}				1.2×10^{6}
Waste canisters					
0.76 x 3.05 m	9.7×10^{4}				9.7×10^{4}
0.3 x 3 m	1.3×10^{5}				1.3×10^{5}
Cardboard boxes (30 x 30 x 60 cm)	2.0×10^{6}	1.4×10^{5}			2.1×10^{6}
Plastic sheets, m^2	1.3×10^{5}				1.3×10^{5}
Filters	6.5×10^{4}				6.5×10^{4}
Plywood, m^2	6.9×10^{5}				6.9×10^{5}
Utilities					
Water consumed, m^3	8.9×10^{7}	2.5×10^{5}		--	8.9×10^{7}
Electricity, kWh	1.8×10^{10}	4.2×10^{8}		1.4×10^{10}	3.2×10^{10}
Steam, MT	--	--		8.4×10^{7}	8.4×10^{7}
Diesel fuel, m^3	4.9×10^{3}	1.6×10^{4}	1.3×10^{6}	1.4×10^{6}	2.7×10^{6}
Propane, m^3	2.0×10^{7}	3.0×10^{6}		--	2.3×10^{7}
Oil, m^3	7.7×10^{4}	--		--	7.7×10^{4}
Coal, MT	--	--		7.8×10^{6}	7.8×10^{6}
Manpower, man-yr	3.0×10^{4}	2.6×10^{3}		1.3×10^{5}	1.6×10^{5}

In terms of energy requirements, the equivalent of about 0.1% of the electricity produced in the reference nuclear power plants through the year 2050 will be required for operating the various waste management facilities. All electricity uses are not accounted for in the total given in Tables 10.3-15 through 10.3-18. It is believed, however, that use of electricity in the formation of resource materials will not add significantly to the total electricity used. For example, for either aluminum or cement, which are relatively energy intensive in their formation, about 8×10^7 kWh are required. This requirement would not add significantly to the 3×10^{10} kWh required for operating the facilities.

Table 10.3-19 gives annual water requirements associated with operation of production and of integrated waste management system facilities. Because water resources would be expected to be replenished annually, water use is given in annual terms rather than total. Annual water use for the waste management facilities is a small fraction of that used in the production facilities. The impact of water use is highly site specific and a detailed analysis would be required for impacts on water sources if and when such facilities are planned. As long as water can be obtained from sources such as the R River, the demands for water for waste management can be easily met.

TABLE 10.3-19. Annual Water Use Associated with Operation of Production (FRP and MOX FFP) and Integrated Waste Management System Facilities, m^3/yr

	FRP	Waste Management Facilities at FRP	MOX FFP	Waste Management Facilities at MOX FFP
Cooling water				
Cooling tower				
Circulating	4.7×10^7	1.7×10^6	2.0×10^6	3.1×10^4
Evaporated	9.8×10^5	3.4×10^4	3.8×10^4	6.2×10^2
Drift	4.7×10^3	1.7×10^2	9.5×10^1	3.1
Blowdown returned to source	1.7×10^5	5.6×10^3	6.9×10^3	1.0×10^2
Makeup withdrawn from source	1.1×10^6	4.0×10^4	4.4×10^4	7.1×10^2
Process water		5.1×10^4		1.9×10^3

Diesel fuel consumed through the year 2050 in support of waste management activities was determined to be $2.7\text{-}3.1 \times 10^6$ m^3. Over the same 70-year period, the amount of diesel fuel used in the United States, if used at a rate of 4×10^7 m^3/yr (nominal annual rate for 1972 to 1975), would amount to about 7.8×10^8 m^3. Thus, diesel fuel consumption would add about 0.4% to the existing U.S. requirements.

The use of propane for incineration of combustible wastes through the year 2050 was estimated at 2.3×10^7 m^3. The average annual use of propane in the United States (1973 to 1975) was about 3.7×10^7 m^3. If this use rate continued over the 70-year period ending in 2050, a total U.S. requirement would be 2.6×10^9 m^3. Thus, propane required in waste management would result in an approximately 0.9% increase in the U.S. requirements over that period.

Process Effluents

The major nonradioactive effluent released from the integrated system facilities would be dust emissions at repositories, particularly salt dust. Other nonradioactive pollutants released to the biosphere during the operational life of the facilities are given in Tables 10.3-20 through 10.3-23.

TABLE 10.3-20. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option - with Prompt Disposal in Salt Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	6 Repositories	Total
Hydrogen chloride, MT	3.4×10^{1}	2.4	--	--	3.6×10^{1}
Carbon monoxide, MT	6.1×10^{1}	5.1	4.6×10^{4}	1.7×10^{4}	6.3×10^{4}
Nitrogen oxide, MT	2.8×10^{2}	9.9	8.5×10^{4}	1.0×10^{5}	1.8×10^{5}
Sulfur oxide, MT	6.1×10^{1}	4.5	7.9×10^{3}	7.2×10^{4}	8.0×10^{4}
Particulates, MT	1.0×10^{2}	1.1×10^{1}	3.8×10^{3}	3.1×10^{3}	6.9×10^{3}
Ammonia, MT	2.0×10^{3}				2.0×10^{3}
Argon, MT	2.4×10^{3}				2.4×10^{3}
Organic acids, MT			3.9×10^{2}		3.9×10^{2}
Aldehydes, MT			3.0×10^{2}		3.0×10^{2}
Hydrocarbons, MT			1.2×10^{4}	6.0×10^{3}	1.8×10^{4}
Nitrogen, MT	2.4×10^{5}				2.4×10^{5}
Oxygen, MT	1.5×10^{5}				1.5×10^{5}
Hydrogen, MT	1.6×10^{2}				1.6×10^{2}
Helium, MT	2.0×10^{1}				2.0×10^{1}
Heat, MJ	8.1×10^{11}	2.9×10^{10}	--	4.6×10^{9}	8.4×10^{11}

TABLE 10.3-21. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option - with Prompt Disposal in Granite Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	7 Repositories	Total
Hydrogen chloride, MT	3.4×10^{1}	2.4	--	--	3.6×10^{1}
Carbon monoxide, MT	6.1×10^{1}	5.1	4.6×10^{4}	2.1×10^{4}	6.7×10^{4}
Nitrogen oxide, MT	2.8×10^{2}	9.9	8.5×10^{4}	1.3×10^{5}	2.2×10^{5}
Sulfur oxide, MT	6.1×10^{1}	4.5	7.9×10^{3}	8.4×10^{4}	9.2×10^{4}
Particulates, MT	1.0×10^{2}	1.1×10^{1}	3.8×10^{3}	3.8×10^{3}	7.7×10^{3}
Ammonia, MT	2.0×10^{3}				2.0×10^{3}
Argon, MT	2.4×10^{3}				2.4×10^{3}
Organic acids, MT			3.9×10^{2}		3.9×10^{2}
Aldehydes, MT			3.0×10^{2}		3.0×10^{2}
Hydrocarbons, MT			1.2×10^{4}	7.7×10^{3}	2.0×10^{4}
Nitrogen, MT	2.4×10^{5}				2.4×10^{5}
Oxygen, MT	1.5×10^{5}				1.5×10^{5}
Hydrogen, MT	1.6×10^{2}				1.6×10^{2}
Helium, MT	2.0×10^{1}				2.0×10^{1}
Heat, MJ	8.1×10^{11}	2.9×10^{10}		5.8×10^{9}	8.4×10^{11}

TABLE 10.3-22. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option - with Prompt Disposal in Shale Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	10 Repositories	Total
Hydrogen chloride, MT	3.4×10^1	2.4	--	--	3.6×10^1
Carbon monoxide, MT	6.1×10^1	5.1	4.6×10^4	2.0×10^4	6.6×10^4
Nitrogen oxide, MT	2.8×10^2	9.9	8.5×10^4	1.2×10^5	2.1×10^5
Sulfur oxide, MT	6.1×10^1	4.5	7.9×10^3	7.8×10^4	8.6×10^4
Particulates, MT	1.0×10^2	1.1×10^1	3.8×10^3	3.5×10^3	7.4×10^3
Ammonia, MT	2.0×10^3				2.0×10^3
Argon, MT	2.4×10^3				2.4×10^3
Organic acids, MT	--		3.9×10^2		3.9×10^2
Aldehydes, MT	--		3.0×10^2		3.0×10^2
Hydrocarbons, MT	--		1.2×10^4	7.1×10^3	1.9×10^4
Nitrogen, MT	2.4×10^5				2.4×10^5
Oxygen, MT	1.5×10^5				1.5×10^5
Hydrogen, MT	1.6×10^2				1.6×10^2
Helium, MT	2.0×10^1				2.0×10^1
Heat, MJ	8.1×10^{11}	2.9×10^{10}		4.3×10^9	8.4×10^{11}

TABLE 10.3-23. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option - with Prompt Disposal in Basalt Repositories

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	6 Repositories	Total
Hydrogen chloride, MT	3.4×10^1	2.4	--	--	3.6×10^1
Carbon monoxide, MT	6.1×10^1	5.1	4.6×10^4	1.6×10^4	6.2×10^4
Nitrogen oxide, MT	2.8×10^2	9.9	8.5×10^4	1.0×10^5	1.8×10^5
Sulfur oxide, MT	6.1×10^1	4.5	7.9×10^3	6.6×10^4	7.4×10^4
Particulates, MT	1.0×10^2	1.1×10^1	3.8×10^3	2.9×10^3	6.7×10^3
Ammonia, MT	2.0×10^3				2.0×10^3
Argon, MT	2.4×10^3				2.4×10^3
Organic acids, MT	--		3.9×10^2		3.9×10^2
Aldehydes, MT	--		3.0×10^2		3.0×10^2
Hydrocarbons, MT	--		1.2×10^4	5.9×10^3	1.8×10^4
Nitrogen, MT	2.4×10^5				2.4×10^5
Oxygen, MT	1.5×10^5				1.5×10^5
Hydrogen, MT	1.6×10^2				1.6×10^2
Helium, MT	2.0×10^1				2.0×10^1
Heat, MJ	8.1×10^{11}	2.9×10^{10}		4.2×10^9	8.4×10^{11}

Routine releases of radioactive material from all the facilities will consist of naturally occurring radon and its decay products from the repository and radionuclides released during

operation of the FRPs and MOX FFPs. Direct radiation will emanate from wastes during transport from one facility to another. Radionuclides released to the biosphere are listed in Tables 10.3-24 through 10.3-27.

TABLE 10.3-24. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option, 1980-2050, with Prompt Disposal in Salt Repositories, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	6 Repositories	Total
^{3}H	1.5×10^{8}			1.5×10^{8}
^{14}C	1.4×10^{6}			1.4×10^{6}
^{85}Kr	3.4×10^{8}			3.4×10^{8}
^{90}Sr	1.1×10^{-2}			1.1×10^{-2}
^{106}Ru	1.5×10^{3}			1.5×10^{3}
^{129}I	4.5×10^{1}			4.5×10^{1}
^{137}Cs	1.6×10^{-2}			1.6×10^{-2}
^{210}Pb			7.8×10^{-7}	7.8×10^{-7}
^{210}Bi			9.6×10^{-3}	9.6×10^{-3}
^{212}Pb			1.0×10^{-5}	1.0×10^{-5}
^{214}Pb			9.6×10^{-3}	9.6×10^{-3}
^{220}Rn			6.6×10^{-3}	6.6×10^{-3}
^{222}Rn			9.6×10^{-3}	9.6×10^{-3}
^{236}U	1.1			1.1
^{238}U	1.3			1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}		7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}		1.1×10^{-2}
^{241}Pu	1.5	1.1		2.6
^{241}Am		8.7×10^{-1}		8.7×10^{-1}

Physical, Chemical, and Thermal Effects

Atmospheric effects resulting from operations of these facilities would include air quality impacts resulting from emission of nonradioactive pollutants, release of sensible heat, and emission of fugitive salt from material excavated from the repository.

Potentially, the greatest effect would be from the salt dust emissions from excavated materials. Although the largest removal of salt occurs during the operational phase of the waste repository, the postulated salt depositions that would result from the total mined material were discussed under construction impacts in Section 10.3.1.

TABLE 10.3-25. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option, 1980-2050, with Prompt Disposal in Granite Repositories, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	7 Repositories	Total
^{3}H	1.5×10^{8}			1.5×10^{8}
^{14}C	1.4×10^{6}			1.4×10^{6}
^{85}Kr	3.4×10^{8}			3.4×10^{8}
^{90}Sr	1.1×10^{-2}			1.1×10^{-2}
^{106}Ru	1.5×10^{3}			1.5×10^{3}
^{129}I	4.5×10^{1}			4.5×10^{1}
^{137}Cs	1.6×10^{-2}			1.6×10^{-2}
^{210}Pb			7.7×10^{-3}	7.7×10^{-3}
^{210}Bi			9.1×10^{1}	9.1×10^{1}
^{212}Pb			1.5×10^{-1}	1.5×10^{-1}
^{214}Pb			9.1×10^{1}	9.1×10^{1}
^{220}Rn			9.8×10^{1}	9.8×10^{1}
^{222}Rn			9.1×10^{1}	9.1×10^{1}
^{236}U	1.1			1.1
^{238}U	1.3			1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}		7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}		1.1×10^{-2}
^{241}Pu	1.5	1.1		2.6
^{241}Am		8.7×10^{-1}		8.7×10^{-1}

TABLE 10.3-26. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option, 1980-2050, with Prompt Disposal in Shale Repositories, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	10 Repositories	Total
^{3}H	1.5×10^{8}			1.5×10^{8}
^{14}C	1.4×10^{6}			1.4×10^{6}
^{85}Kr	3.4×10^{8}			3.4×10^{8}
^{90}Sr	1.1×10^{-2}			1.1×10^{-2}
^{106}Ru	1.5×10^{3}			1.5×10^{3}
^{129}I	4.5×10^{1}			4.5×10^{1}
^{137}Cs	1.6×10^{-2}			1.6×10^{-2}
^{210}Pb			2.5×10^{-3}	2.5×10^{-3}
^{210}Bi			6.0×10^{1}	6.0×10^{1}
^{212}Pb			7.7×10^{-2}	7.7×10^{-2}
^{214}Pb			6.0×10^{1}	6.0×10^{1}
^{220}Rn			5.1×10^{1}	5.1×10^{1}
^{222}Rn			6.0×10^{1}	6.0×10^{1}
^{236}U	1.1			1.1
^{238}U	1.3			1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}		7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}		1.1×10^{-2}
^{241}Pu	1.5	1.1		2.6
^{241}Am		8.7×10^{-1}		8.7×10^{-1}

TABLE 10.3-27. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option, 1980-2050, with Prompt Disposal in Basalt Repositories, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	6 Repositories	Total
^{3}H	1.5×10^{8}			1.5×10^{8}
^{14}C	1.4×10^{6}			1.4×10^{6}
^{85}Kr	3.4×10^{8}			3.4×10^{8}
^{90}Sr	1.1×10^{-2}			1.1×10^{-2}
^{106}Ru	1.5×10^{3}			1.5×10^{3}
^{129}I	4.5×10^{1}			4.5×10^{1}
^{137}Cs	1.6×10^{-2}			1.6×10^{-2}
^{210}Pb			8.4×10^{-4}	8.4×10^{-4}
^{210}Bi			1.0×10^{1}	1.0×10^{1}
^{212}Pb			1.8×10^{-2}	1.8×10^{-2}
^{214}Pb			1.0×10^{1}	1.0×10^{1}
^{220}Rn			1.2×10^{1}	1.2×10^{1}
^{222}Rn			1.0×10^{1}	1.0×10^{1}
^{236}U	1.1			1.1
^{238}U	1.3			1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}		7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}		1.1×10^{-2}
^{241}Pu	1.5	1.1		2.6
^{241}Am		8.7×10^{-1}		8.7×10^{-1}

Heat rejection during rail and truck shipments of waste would be several orders of magnitude lower than the heat load at a stationary facility, which is considered to have only microclimatic effects; as a consequence, no significant atmospheric effects are postulated. Both the heat loads and combustion product releases amount to a very small increment over total present releases associated with rail and truck transport.

Table 10.3-28 lists the concentrations of nonradioactive pollutants (e.g., combustion products in the atmosphere) at the facility fenceline from burning diesel fuel and chemicals. These concentrations are all less than federal ambient air quality standards and no significant ecological effects are expected.

The atmospheric effects, visible plume lengths, and drift deposition caused by heat rejection associated with waste management activities from the FRP and MOX FFP cooling towers will be insignificant. Temperature elevations from FRP production and waste management activities will be less than 0.5°C at 1 km downwind and less than a few tenths of a degree at distances beyond 1.6 km. The impacts of water use during plant operation are highly site specific. However, as long as sources such as the R River in the reference environment are used, no effects on aquatic biota would be expected from withdrawal of water or from the discharge of chemicals and heat from process cooling systems.

TABLE 10.3-28. Average Atmospheric Concentrations of Nonradioactive Pollutants Released During Operation of Individual Facilities for the Uranium and Plutonium Recycle Option, 1980-2050, μg/m^3

Pollutant	FRP	MOX FFP	Repository[a]	Air Quality Standard
Nitrogen oxides	0.025	<0.001	8.4	1.0×10^{2}(b,d)
Carbon monoxide	0.001	<0.001	1.0	4×10^{4}(b,d)
Sulfur oxide	<0.001	<0.001	2.5	8.0×10^{1}(b,e)
Ammonia	0.2			1.8×10^{4}(c)
Hydrochloric acid	<0.001	<0.001		7.0×10^{3}(c)
Argon	0.007			1.5×10^{7}(b)
Nitrogen	0.5			8.7×10^{8}(b)
Oxygen	0.3			2.7×10^{8}(b)
Hydrogen	<0.001			4.0×10^{1}(b)
Helium	<0.001			
Particulates	<0.001	<0.001	0.6	7.5×10^{1}(a)

a. Air concentrations are expected to be approximately equal for repositories in the four geologic media.
b. A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.[3]
c. Threshold Limit Values for Current Year (1976), American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.[4]
d. One-hour average not to be exceeded more than once per year.
e. Annual average never to be exceeded, i.e., annual geometric mean.

Radiological Effects

Radiation doses in the vicinity of the facilities for the uranium and plutonium recycle option during normal operations were calculated based on the radioactive releases listed in Tables 10.3-24 through 10.3-27. These doses were based on releases from mining operations, reprocessing and fuel fabrication operations, and transportation of waste from FRPs and MOX FFPs to geologic repositories. The only exposure pathway to man and to the environment is via airborne effluents, since there are no planned releases to ground or water. Normal releases from the repositories are naturally occurring radon and its decay products liberated from mined material. Release/dose factors and dose by 5-yr intervals are presented in Appendix D.

The 70-year doses from all pathways to the population within 80 km, the worldwide population, and the work force are given in Tables 10.3-29 through 10.3.32.

For the period of analysis of 1980 to 2050, six to 50 radiation-related health effects would result from the total regional man-rem dose, assuming 100 to 800 health effects per million man-rem. For the worldwide population, 110 to 900 such health effects were estimated to result.

TABLE 10.3-29. 70-Year Total Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Salt Repositories, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	6 Repositories	Total	Dose From Naturally Occurring Sources
Regional population	5.6×10^4	1.8×10^1	9.3×10^2	5.1×10^{-2}	5.7×10^4	1.4×10^7[a]
Worldwide population	1.1×10^6	0	0	0	1.1×10^6	4.6×10^{10}
Work force	9.5×10^4	2.7×10^4	4.8×10^4	4.0×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

TABLE 10.3-30. 70-Year Total Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Granite Repositories, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	7 Repositories	Total	Dose From Naturally Occurring Sources
Regional population	5.6×10^4	1.8×10^1	9.3×10^2	4.8×10^2	5.7×10^4	1.4×10^7[a]
Worldwide population	1.1×10^6	0	0	0	1.1×10^6	4.6×10^{10}
Work force	9.5×10^4	2.7×10^4	4.8×10^4	4.0×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

TABLE 10.3-31. 70-Year Total Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Shale Repositories, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	10 Repositories	Total	Dose From Naturally Occurring Sources
Regional population	5.6×10^4	1.8×10^1	9.3×10^2	3.2×10^2	5.7×10^4	1.4×10^7[a]
Worldwide population	1.1×10^6	0	0	0	1.1×10^6	4.6×10^{10}
Work force	9.5×10^4	2.7×10^4	4.8×10^4	4.0×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

TABLE 10.3-32. 70-Year Total Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Prompt Disposal in Basalt Repositories, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	6 Repositories	Total	Dose From Naturally Occurring Sources
Regional population	5.6×10^4	1.8×10^1	9.3×10^2	5.5×10^1	5.7×10^4	1.4×10^7 (a)
Worldwide population	1.1×10^6	0	0	0	1.1×10^6	4.6×10^{10}
Work force	9.5×10^4	2.7×10^4	4.8×10^4	4.0×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

Ecological Effects

The major adverse ecological impacts from uranium and plutonium fuel recycle are believed to be, as in the case of the once-through cycle, the deposition of salt associated with construction and operation of the geologic repository in salt. The problem is not likely to be insurmountable; however, careful attention will need to be paid to the movement and storage of salt when specific facilities are constructed. The effects to be expected from salt handling are treated in Section 10.1.1. Deposition of nonradioactive pollutants from ventilation and machinery operation would be well below the threshold of environmental effects.

Impacts o the terrestrial environment from effluents other than salt dust will be limited to cooling tower drift. Modern cooling towers exhibit very small fractions of circulating cooling water (0.0001 and below) as drift. Deposition of drift-derived salts from radioactive waste management is believed to be insignificant. In terms of thermal impact, the temperature increases beyond site boundaries will be only a few tenths of a degree. Thus, planned heat releases are not expected to have any adverse effect on terrestrial ecosystems.

A significant beneficial impact on terrestrial biota will be the reduction in human activity as a result of security requirements in restricted areas at waste management facilities. These conditions should provide for a substantial increase in relatively undisturbed terrestrial habitat.

Water use at the waste management facilities where water is taken from sources such as the R River in the reference or similar environment should have no significant impact on aquatic ecosystems.

Accidents

In the previous sections postulated accidents are described for operation* of each facility. Whatever accident probabilities are postulated for plants or processes can thus be multiplied by the total number of plants or processes to obtain the probability of the accident occurring for the integrated system. The acute environmental consequences to the reference environment

* In this context, mining of repositories is classed as construction.

would not necessarily be increased by the number of plants because the accident would involve different regional populations for each plant. However, the risk to U.S. society of consequences associated with possible accidents would be increased by the number of plants operating.

REFERENCES FOR SECTION 10.3

1. Air Quality Impacts Due to Construction at LWR Waste Management Facilities, URS 7043-01-01, URS Company, June 1977.

2. Accident Facts, National Safety Council, Chicago, IL, 1974.

3. A. C. Stern, H. D. Wohlers, R. W. Bonbel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

4. Threshold Limit Values for Current Year (1976), American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.

10.4 ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT IN THE DEFERRED REPROCESSING OPTION

10.4 ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT IN THE DEFERRED REPROCESSING OPTION

In this option, spent fuel is removed from reactors and placed in reactor spent fuel storage basins for a minimum of one-half year. Because of self-heating considerations in dry packaging, spent fuel is assumed to be aged (cooled) for 6-1/2 years before packaging and delivery to an extended spent fuel storage facility (ESFSF) for extended storage. It is assumed that 25% of reactors will not have onsite storage capacity for aging fuel 6-1/2 years, and that fuel from these reactors is shipped to an independent spent fuel storage facility (ISFSF) for storage before packaging. The other 75% of reactor fuel is aged at the reactor and then sent to the ISFSF for packaging before shipment to the ESFSF.

The decision is assumed to be made in the year 2000 that spent fuel from LWRs will be reprocessed. If the facilities for reprocessing are not then available, spent fuel will have to remain in the ESFSF until the facilities are ready.

Although spent fuel in this option is a resource and not a waste, discussion of its management is included for completeness.

The flow of spent fuel and reprocessing wastes is shown in Figure 10.4-1 for deferred reprocessing of uranium and plutonium recycle.

The following plants and/or functions would be required in addition to those described for uranium and plutonium recycle (Section 10.3):

- addition of the equivalent of 8 ESFSFs,
- addition of 14 ISFSFs,
- reduction of 4 MOX FFPs because of the reduced need for plutonium in LWRs from 1980 to 2050.

10.4.1 Resource Commitments

Resource commitments associated with the construction of fuel reprocessing waste management facilities under the reference deferred reprocessing option (for the four geologic media) are presented in Tables 10.4-1 through 10.4-4. The addition of 8 ESFSs and 14 ISFSFs requires commitment of two to three times more resources for construction than those required for the prompt disposal option. It is believed that these quantities, when committed over a 15- to 45-year period, will not impact significantly on other U.S. industrial needs. Materials needed for operation of the additional facilities do not appear to be noteworthy. As long as ISFSFs are not colocated and are sited near rivers such as the R River in the reference or similar environment, additional demands for water can be easily met. Operational energy commitments for the deferred reprocessing option are summarized in Tables 10.4-5 through 10.4-8. About 5×10^{10} kWh are required in this option, which is about 50% more than that required in the prompt reprocessing option, and represents about 0.05% of the total electricity to be produced in the reference LWR scenario.

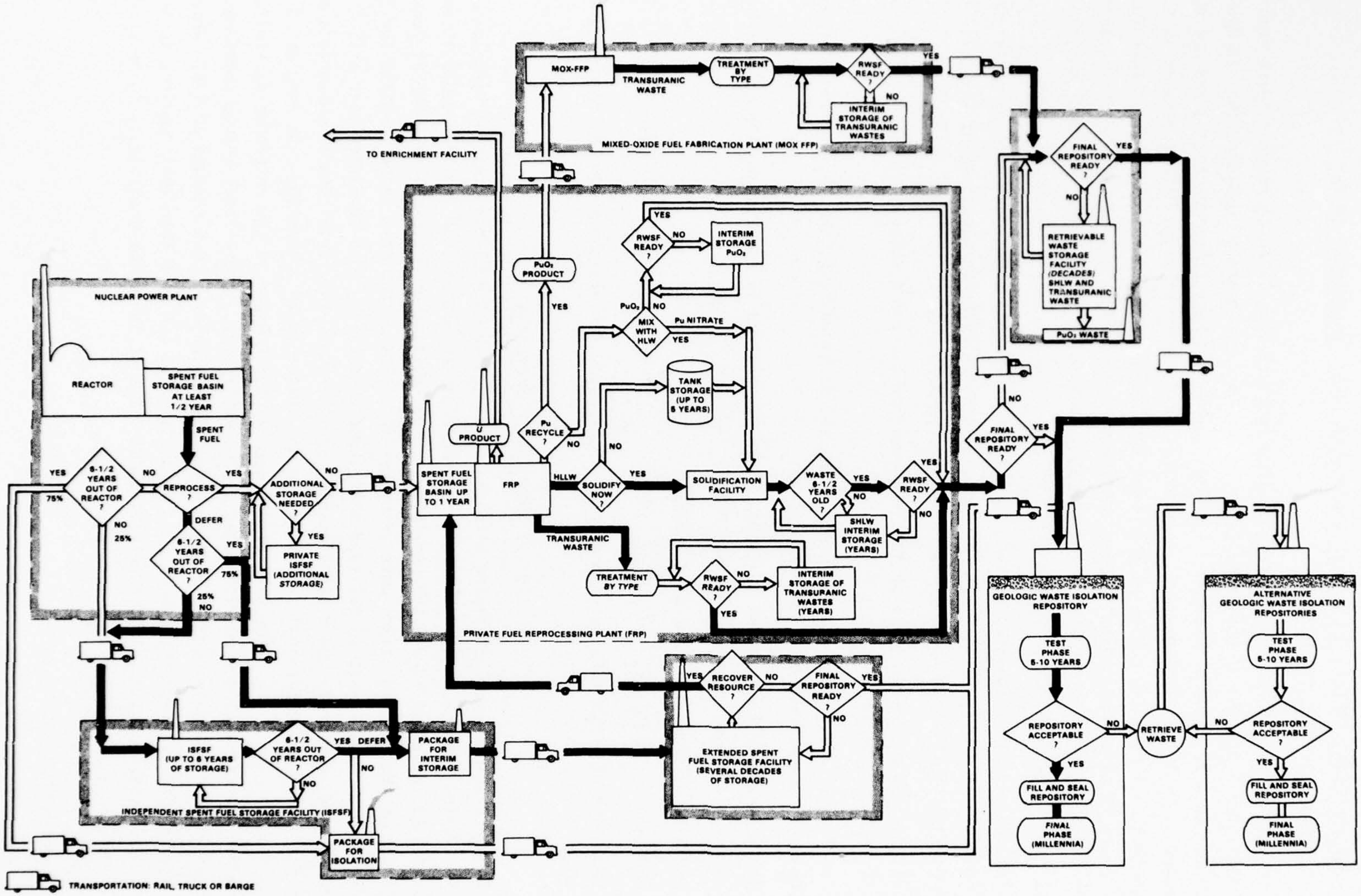

FIGURE 10.4-1. Flow of Spent Fuel and Wastes (Outlined in Black) in the Deferred Reprocessing Cycle

TABLE 10.4-1. Resource Commitments Associated with Construction of Fuel Reprocessing Management Facilities Under the Deferred Uranium and Plutonium Recycle Option with Disposal in Salt Repositories

Resource	Waste Management at 6.75 FRPs	Waste Management at 6.0 MOX FFPs	6 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Increase Over Prompt Reprocessing
Land, ha								
Structures	1.3×10^2	2.0	1.1×10^3		1.0×10^3	1.4×10^2	2.4×10^3	100
Access roads and railroads	---	---	4.8×10^1		1.1×10^2	1.9×10^2	3.5×10^2	630
Mineral and surface rights (property)	---	---	4.9×10^3		3.2×10^3	5.6×10^3	1.4×10^4	190
Water, m^3	9.4×10^5	3.5×10^4	1.6×10^6		3.2×10^5	1.4×10^6	4.3×10^6	65
Materials								
Concrete, m^3	5.3×10^5	1.8×10^4	6.6×10^5		9.3×10^4	6.5×10^5	2.0×10^6	67
Steel, MT	1.2×10^5	4.0×10^3	1.1×10^5	2.3×10^3	2.1×10^5	2.1×10^5	6.6×10^5	180
Copper, MT	1.4×10^3	4.1×10^1	1.4×10^3			6.3×10^2	3.5×10^3	21
Zinc, MT	7.4×10^2		3.7×10^2			9.1×10^2	2.0×10^3	82
Aluminum, MT	3.4×10^1		2.8×10^2				3.1×10^2	0
Lumber, m^3	3.4×10^4	1.1×10^3	1.6×10^4		1.5×10^3	4.6×10^4	9.9×10^4	90
Lead, MT	4.4×10^2			5.2×10^3	5.1×10^2		6.2×10^3	11
Chromium, MT (in SS)				4.1×10^2			4.1×10^2	0
Nickel, MT (in SS)				1.8×10^2			1.8×10^2	0
Energy								
Propane, m^3	8.8×10^3	2.5×10^2	1.4×10^4		6.1×10^3	1.3×10^4	4.2×10^4	83
Diesel fuel, m^3	8.1×10^4	2.5×10^3	1.4×10^5		6.4×10^4	1.3×10^5	4.2×10^5	91
Gasoline, m^3	5.9×10^4	1.9×10^3	1.1×10^5		4.3×10^4	8.9×10^4	3.0×10^5	76
Electricity, kWh	4.3×10^7	1.7×10^6	9.6×10^7		3.2×10^7	6.5×10^7	2.4×10^8	71
Manpower, man-yr	4.0×10^4	1.1×10^3	6.6×10^4		2.7×10^4	5.6×10^4	1.9×10^5	73

TABLE 10.4-2. Resource Commitments Associated with Construction of Fuel Reprocessing Management Facilities Under the Deferred Uranium and Plutonium Recycle Option with Disposal in Granite Repositories

Resource	Waste Management at 6.75 FRPs	Waste Management at 6.0 MOX FFPs	7 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Increase Over Prompt Reprocessing
Land, ha								
Structures	1.3×10^2	2.0	1.5×10^3		1.0×10^3	1.4×10^2	2.8×10^3	75
Access roads and railroads	---	---	5.6×10^1		1.1×10^2	1.9×10^2	3.6×10^2	540
Mineral and surface rights (property)	---	---	5.7×10^3		3.2×10^3	5.6×10^3	1.5×10^4	160
Water, m^3	9.4×10^5	3.5×10^4	3.6×10^6		3.2×10^5	1.4×10^6	6.3×10^6	37
Materials								
Concrete, m^3	5.3×10^5	1.8×10^4	1.5×10^6		9.3×10^4	6.5×10^5	2.8×10^6	33
Steel, MT	1.2×10^5	4.0×10^3	2.3×10^5	2.3×10^3	2.1×10^5	2.1×10^5	7.8×10^5	120
Copper, MT	1.4×10^3	4.1×10^1	3.3×10^3			6.3×10^2	5.4×10^3	13
Zinc, MT	7.4×10^2		8.4×10^2			9.1×10^2	2.5×10^3	56
Aluminum, MT	3.4×10^1		6.3×10^2				6.6×10^2	0
Lumber, m^3	3.4×10^4	1.1×10^3	3.4×10^4		1.5×10^3	4.6×10^4	1.2×10^5	71
Lead, MT	4.4×10^2			5.2×10^3	5.1×10^2		6.2×10^3	11
Chromium, MT (in SS)				4.1×10^2			4.1×10^2	0
Nickel, MT (in SS)				1.8×10^2			1.8×10^2	0
Energy								
Propane, m^3	8.8×10^3	2.5×10^2	3.2×10^4		6.1×10^3	1.3×10^4	6.0×10^4	46
Diesel fuel, m^3	8.1×10^4	2.5×10^3	3.2×10^5		6.4×10^4	1.3×10^5	6.0×10^5	50
Gasoline, m^3	5.9×10^4	1.9×10^3	2.3×10^5		4.3×10^4	8.9×10^4	4.2×10^5	45
Electricity, kWh	4.3×10^7	1.7×10^6	2.1×10^8		3.2×10^7	6.5×10^7	3.5×10^8	35
Manpower, man-yr	4.0×10^4	1.1×10^3	1.5×10^5		2.7×10^4	5.6×10^4	2.7×10^5	42

TABLE 10.4-3. Resource Commitments Associated with Construction of Fuel Reprocessing Management Facilities Under the Deferred Uranium and Plutonium Recycle Option with Disposal in Shale Repositories

Resource	Waste Management at 6.75 FRPs	Waste Management at 6.0 MOX FFPs	10 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Increase Over Prompt Reprocessing
Land, ha								
Structures	1.3×10^2	2.0	1.8×10^3		1.0×10^3	1.4×10^2	3.1×10^3	63
Access roads and railroads	---	---	8.0×10^1		1.1×10^2	1.9×10^2	3.8×10^2	380
Mineral and surface rights (property)	---	---	8.1×10^3		3.2×10^3	5.6×10^3	1.7×10^4	110
Water, m^3	9.4×10^5	3.5×10^4	2.9×10^6		3.2×10^5	1.4×10^6	5.6×10^6	44
Materials								
Concrete, m^3	5.3×10^5	1.8×10^4	1.2×10^6		9.3×10^4	6.5×10^5	2.5×10^6	39
Steel, MT	1.2×10^5	4.0×10^3	1.9×10^5	2.3×10^3	2.1×10^5	2.1×10^5	7.4×10^5	130
Copper, MT	1.4×10^3	4.1×10^1	2.6×10^3			6.3×10^2	4.7×10^3	15
Zinc, MT	7.4×10^2		6.7×10^2			9.1×10^2	2.3×10^3	64
Aluminum, MT	3.4×10^1		5.0×10^2				5.3×10^2	0
Lumber, m^3	3.4×10^4	1.1×10^3	2.8×10^4		1.5×10^3	4.6×10^4	1.1×10^5	72
Lead, MT	4.4×10^2			5.2×10^3	5.1×10^2		6.2×10^3	11
Chromium, MT (in SS)				4.1×10^2			4.1×10^2	0
Nickel, MT (in SS)				1.8×10^2			1.8×10^2	0
Energy								
Propane, m^3	8.8×10^3	2.5×10^2	2.6×10^4		6.1×10^3	1.3×10^4	5.4×10^4	54
Diesel fuel, m^3	8.1×10^4	2.5×10^3	2.6×10^5		6.4×10^4	1.3×10^5	5.4×10^5	54
Gasoline, m^3	5.9×10^4	1.9×10^3	1.9×10^5		4.3×10^4	8.9×10^4	3.8×10^5	52
Electricity, kWh	4.3×10^7	1.7×10^6	1.7×10^8		3.2×10^7	6.5×10^7	3.1×10^8	41
Manpower, man-yr	4.0×10^4	1.1×10^3	1.3×10^5		2.7×10^4	5.6×10^4	2.5×10^5	47

TABLE 10.4-4. Resource Commitments Associated with Construction of Fuel Reprocessing Management Facilities Under the Deferred Uranium and Plutonium Recycle Option with Disposal in Basalt Repositories

Resource	Waste Management at 6.75 FRPs	Waste Management at 6.0 MOX FFPs	6 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Increase Over Prompt Reprocessing
Land, ha								
Structures	1.3×10^2	2.0	1.3×10^3		1.0×10^3	1.4×10^2	2.6×10^3	86
Access roads and railroads	---	---	4.8×10^1		1.1×10^2	1.9×10^2	3.5×10^2	630
Mineral and surface rights (property)	---	---	4.9×10^3		3.2×10^3	5.6×10^3	1.4×10^4	190
Water, m^3	9.4×10^5	3.5×10^4	2.7×10^6		3.2×10^5	1.4×10^6	5.4×10^6	46
Materials								
Concrete, m^3	5.3×10^5	1.8×10^4	1.1×10^6		9.3×10^4	6.5×10^5	2.4×10^6	41
Steel, MT	1.2×10^5	4.0×10^3	1.8×10^5	2.3×10^3	2.1×10^5	2.1×10^5	7.3×10^5	140
Copper, MT	1.4×10^3	4.1×10^1	2.5×10^3			6.3×10^2	4.6×10^3	15
Zinc, MT	7.4×10^2		6.6×10^2			9.1×10^2	2.3×10^3	64
Aluminum, MT	3.4×10^1		4.6×10^2				4.9×10^2	0
Lumber, m^3	3.4×10^4	1.1×10^3	2.6×10^4		1.5×10^3	4.6×10^4	1.1×10^5	77
Lead, MT	4.4×10^2			5.2×10^3	5.1×10^2		5.7×10^3	2
Chromium, MT (in SS)				4.1×10^2			4.1×10^2	0
Nickel, MT (in SS)				1.8×10^2			1.8×10^2	0
Energy								
Propane, m^3	8.8×10^3	2.5×10^2	2.4×10^4		6.1×10^3	1.3×10^4	5.2×10^4	58
Diesel fuel, m^3	8.1×10^4	2.5×10^3	2.4×10^5		6.4×10^4	1.3×10^5	5.2×10^5	58
Gasoline, m^3	5.9×10^4	1.9×10^3	1.6×10^5		4.3×10^4	8.9×10^4	3.5×10^5	59
Electricity, kWh	4.3×10^7	1.7×10^6	1.6×10^8		3.2×10^7	6.5×10^7	3.0×10^8	43
Manpower, man-yr	4.0×10^4	1.1×10^3	1.6×10^5		2.7×10^4	5.6×10^4	2.8×10^5	40

TABLE 10.4-5. Energy Commitments Associated with Operation of the Deferred Fuel Reprocessing Facilities for the Deferred Uranium and Plutonium Recycle Option Through the Year 2050 with Prompt Disposal in Salt Repositories

Energy Source	6.75 FRPs	6 MOX FFPs	6 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Propane, m^3	2.0×10^7	1.8×10^6	---	---	---	---	3.2×10^7	+39
Diesel fuel, m^3	4.9×10^3	9.6×10^3	1.5×10^6	1.3×10^6	2.9×10^4	---	2.8×10^6	0
Coal, MT	---	---	8.4×10^6	---	---	3.7×10^6	1.2×10^7	+43
Electricity, kWh	1.8×10^{10}	2.5×10^8	1.3×10^{10}	---	1.3×10^9	1.4×10^{10}	4.6×10^{10}	+48
Manpower, man-yr	3.0×10^4	1.6×10^3	1.1×10^5	---	7.7×10^3	6.7×10^4	2.1×10^5	+50

TABLE 10.4-6. Energy Commitments Associated with Operation of the Deferred Fuel Reprocessing Facilities for the Deferred Uranium and Plutonium Recycle Option Through the Year 2050 with Prompt Disposal in Granite Repositories

Energy Source	6.75 FRPs	6 MOX FFPs	7 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Propane, m^3	2.0×10^7	1.8×10^6	---	---	---	---	3.2×10^7	+39
Diesel fuel, m^3	4.9×10^3	9.6×10^3	1.8×10^6	1.3×10^6	2.9×10^4	---	3.1×10^6	+11
Coal, MT	---	---	9.8×10^6	---	---	3.7×10^6	1.4×10^7	+67
Electricity, kWh	1.8×10^{10}	2.5×10^8	1.8×10^{10}	---	1.3×10^9	1.4×10^{10}	5.1×10^{10}	+65
Manpower, man-yr	3.0×10^4	1.6×10^3	1.7×10^5	---	7.7×10^3	6.7×10^4	2.8×10^5	+100

TABLE 10.4-7. Energy Commitments Associated with Operation of the Deferred Fuel Reprocessing Facilities for the Deferred Uranium and Plutonium Recycle Option Through the Year 2050 with Prompt Disposal in Shale Repositories

Energy Source	6.75 FRPs	6 MOX FFPs	10 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Propane, m^3	2.0×10^7	1.8×10^6	---	---	---	---	3.2×10^7	+39
Diesel fuel, m^3	4.9×10^3	9.6×10^3	1.7×10^6	1.3×10^6	2.9×10^4	---	3.0×10^6	+7.1
Coal, MT	---	---	9.4×10^6	---	---	3.7×10^6	1.3×10^7	+55
Electricity, kWh	1.8×10^{10}	2.5×10^8	1.4×10^{10}	---	1.3×10^9	1.4×10^{10}	4.7×10^{10}	+52
Manpower, man-yr	3.0×10^4	1.6×10^3	1.3×10^5	---	7.7×10^3	6.7×10^4	2.4×10^5	+71

TABLE 10.4-8. Energy Commitments Associated with Operation of the Deferred Fuel Reprocessing Facilities for the Deferred Uranium and Plutonium Recycle Option Through the Year 2050 with Prompt Disposal in Basalt Repositories

Energy Source	6.75 FRPs	6 MOX FFPs	6 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Propane, m^3	2.0×10^7	1.8×10^6	---	---	---	---	3.2×10^7	+39
Diesel fuel, m^3	4.9×10^3	9.6×10^3	1.4×10^6	1.3×10^6	2.9×10^4	---	2.7×10^6	-3.6
Coal, MT	---	---	7.8×10^6	---	---	3.7×10^6	1.2×10^7	+43
Electricity, kWh	1.8×10^{10}	2.5×10^8	1.4×10^{10}	---	1.3×10^9	1.4×10^{10}	4.7×10^{10}	+52
Manpower, man-yr	3.0×10^4	1.6×10^3	1.3×10^5	---	7.7×10^3	6.7×10^4	2.4×10^5	+71

10.4.2 Nonradiological Effects

Tables 10.4-9 through 10.4-12 summarize the nonradiological injuries and fatalities for the deferred reprocessing option. About 1500 disabling injuries and 19 fatalities would be expected during construction of 14 ISFSFs. The construction of eight ESFSFs would add another 730 disabling injuries and about nine fatalities. Deferred reprocessing results in an estimated 30% increase in disabling injuries and a 15% increase in fatalities over prompt reprocessing.

10.4.3 Radiological Effects

Deferred reprocessing will result in the release of decay heat to the atmosphere. Each ESFSF with a packaged fuel receiving facility releases about 7.0×10^8 MJ/yr. Provided these facilities are not colocated, no environmental effect from this release of heat is expected. No significant additions of other nonradioactive pollutants beyond those from prompt reprocessing are expected.

In the deferred reprocessing option, population doses will come principally from ^3H out of the excess water vaporizor at the FRP and from the release of ^3H, ^{14}C, and ^{85}Kr and others from the treated dissolver off gas at the FRP. The doses from the additional ESFSF and ISFSF facilities will not add significantly to the doses resulting from the operation of the FRP. The delay in reprocessing will reduce the amounts of the shorter half-lived radionuclides that are released. Doses from long-lived radionuclides, such as ^{129}I and ^{14}C, will be unchanged. The calculated dose to the worldwide population will be substantially unchanged. The controlling radionuclide is ^{14}C, which does not decay significantly during the delay period. Occupational doses will increase primarily because of the added storage time and maintenance of facilities.

Release/dose factors and dose by 5-year intervals are presented in Appendix D. Seventy-year total body doses resulting from waste management activities in the deferred uranium and plutonium recycle option are presented in Tables 10.4-13 through 10.4-16.

TABLE 10.4-9. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Salt Repositories

	6.75 FRPs	6 MOX FFPs	6 Reposi-tories	Transpor-tation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Injuries	1.1×10^3	3.1×10^1	3.0×10^3	5.0×10^2	7.3×10^2	1.5×10^3	6.9×10^3	+47
Fatalities	1.4×10^1	1.0	6.0×10^1	5.2×10^1	9.0	1.9×10^1	1.6×10^2	+23

TABLE 10.4-10. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Granite Repositories

	6.75 FRPs	6 MOX FFPs	7 Reposi-tories	Transpor-tation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Injuries	1.1×10^3	3.1×10^1	7.7×10^3	5.0×10^2	7.3×10^2	1.5×10^3	1.2×10^4	+28
Fatalities	1.4×10^1	1.0	1.5×10^2	5.2×10^1	9.0	1.9×10^1	2.5×10^2	+14

TABLE 10.4-11. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Shale Repositories

	6.75 FRPs	6 MOX FFPs	10 Reposi-tories	Transpor-tation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Injuries	1.1×10^3	3.1×10^1	5.9×10^3	5.0×10^2	7.3×10^2	1.5×10^3	9.8×10^3	+29
Fatalities	1.4×10^1	1.0	1.2×10^2	5.2×10^1	9.0	1.9×10^1	2.2×10^2	+16

TABLE 10.4-12. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Basalt Repositories

	6.75 FRPs	6 MOX FFPs	6 Reposi-tories	Transpor-tation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing
Injuries	1.1×10^3	3.1×10^1	7.8×10^3	5.0×10^2	7.3×10^2	1.5×10^3	1.2×10^4	+26
Fatalities	1.4×10^1	1.0	1.6×10^2	5.2×10^1	9.0	1.9×10^1	2.6×10^2	+13

The dose to the regional population is reduced by a factor of about 3 when deferred reprocessing is chosen over prompt reprocessing. However, the dose from deferred reprocessing is already small in comparison with that received from naturally occurring sources; therefore, the reduction in dose is not significant. The worldwide population dose remains substantially unchanged. The dose to the process work force is increased about 30%, which does not constitute a significant change.

TABLE 10.4-13. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Salt Repositories, man-rem

	6.75 FRPs	6 MOX FFPs	6 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.1×10^1	5.1×10^{-2}	9.2×10^2	0	7.7	2.5×10^4	-56	1.4×10^7 per facility
Worldwide Population	1.1×10^6	0	0	0	0	3.0×10^2	1.1×10^6	0	4.6×10^{10}
Work Force	9.5×10^4	1.6×10^4	3.6×10^4	4.8×10^4	9.8×10^3	5.1×10^4	2.6×10^5	+24	

TABLE 10.4-14. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Granite Repositories, man-rem

	6.75 FRPs	6 MOX FFPs	7 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.1×10^1	4.8×10^2	9.2×10^2	0	7.7	2.5×10^4	-56	1.4×10^7 per facility
Worldwide Population	1.1×10^6	0	0	0	0	3.0×10^2	1.1×10^6	0	4.6×10^{10}
Work Force	9.5×10^4	1.6×10^4	3.6×10^4	4.8×10^4	9.8×10^3	5.1×10^4	2.6×10^5	+24	

TABLE 10.4-15. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Shale Repositories, man-rem

	6.75 FRPs	6 MOX FFPs	10 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.1×10^1	3.2×10^2	9.2×10^2	0	7.7	2.5×10^4	-56	1.4×10^7 per facility
Worldwide Population	1.1×10^6	0	0	0	0	3.0×10^2	1.1×10^6	0	4.6×10^{10}
Work Force	9.5×10^4	1.6×10^4	3.6×10^4	4.8×10^4	9.8×10^3	5.1×10^4	2.6×10^5	+24	

TABLE 10.4-16. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Deferred Uranium and Plutonium Recycle Option with Disposal in Basalt Repositories, man-rem

	6.75 FRPs	6 MOX FFPs	6 Repositories	Transportation	8 ESFSFs	14 ISFSFs	Total	% Change from Prompt Reprocessing	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.1×10^1	5.5×10^1	9.2×10^2	0	7.7	2.5×10^4	-56	1.4×10^7 per facility
Worldwide Population	1.1×10^6	0	0	0	0	3.0×10^2	1.1×10^6		4.6×10^{10}
Work Force	9.5×10^4	1.6×10^4	3.6×10^4	4.8×10^4	9.8×10^3	5.1×10^4	2.6×10^5	+24	

10.5 ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT IN AN INTEGRATED SYSTEM FOR THE URANIUM AND PLUTONIUM RECYCLE OPTION - WITH WASTE REPOSITORIES UNAVAILABLE UNTIL THE YEAR 2000

10.5 ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE WASTE MANAGEMENT IN AN INTEGRATED SYSTEM FOR THE URANIUM AND PLUTONIUM RECYCLE OPTION - WITH WASTE REPOSITORIES UNAVAILABLE UNTIL THE YEAR 2000

Plants and/or functions for which environmental impacts of radioactive waste management are considered in the uranium and plutonium recycle mode with waste repositories unavailable until the year 2000 are as follows:

- treatment of radioactive gaseous effluents at the fuel reprocessing plant (FRP)
- onplant interim storage of solidified high-level wastes, transuranic wastes, and ^{85}Kr
- transport of wastes to retrievable waste storage facility (RWSF)
- storage of wastes pending availability of repositories
- transport of solidified high-level wastes and transuranic wastes to a geologic repository
- treatment of gaseous effluents at the mixed-oxide fuel fabrication plant (MOX FFP)
- onplant storage of transuranic wastes
- truck transport of MOX FFP transuranic wastes to a geologic repository.

In the uranium and plutonium recycle option with waste repositories unavailable until the year 2000, spent fuel from LWRs will be moved into reactor spent fuel storage basins for at least one-half year. From there it will be transferred to the receiving basin at the FRP, where it will remain until it has cooled 1-1/2 years before reprocessing. At the FRP the fuel will be dissolved and the uranium and plutonium separated out; the uranium will be sent to an enrichment plant and the plutonium to a MOX FFP.

In the reference system, high-level waste from the FRP will be solidified by vitrification, following calcination, and stored until the time out of the reactor reaches 6-1/2 years, at which time it will be sent to a retrievable waste storage facility (RWSF) pending availability of deep geologic repositories. Fuel residues and non-high-level transuranic wastes from the FRP will also be sent to the RWSF. Non-high-level transuranic wastes are failed equipment, noncombustible trash, and wet wastes and incinerator ash that have been immobilized in cement. Krypton that has been removed from dissolver off gas will be stored onsite at the FRP. All wastes generated at the MOX FFP will be assumed to be contaminated with transuranic radionuclides. After packaging, incineration, or immobilization (as appropriate for the waste form) the wastes will be sent to the retrievable waste storage facility pending availability of waste repositories. Waste flow in the uranium and plutonium recycle option is shown in Figure 10.5-1.

During the reference LWR period (1980 to 2050), six 2000-MTHM/yr FRPs, one 1500-MTHM/yr FRP, 10 MOX FFP's, two RWSFs and six geologic waste repositories in salt (or seven in granite, or 10 in shale or six in basalt) will be built and operated. Solidified high-level waste and fuel residues will be transported from the FRP to the RWSF and into the repository by rail. Trucks will be used to transport non-high-level transuranic wastes from the FRP and MOX FFP to the RWSF and into the repository. The environmental effects of construction and operation of this integrated system of plants and of the transportation of the waste is summarized in the following sections.

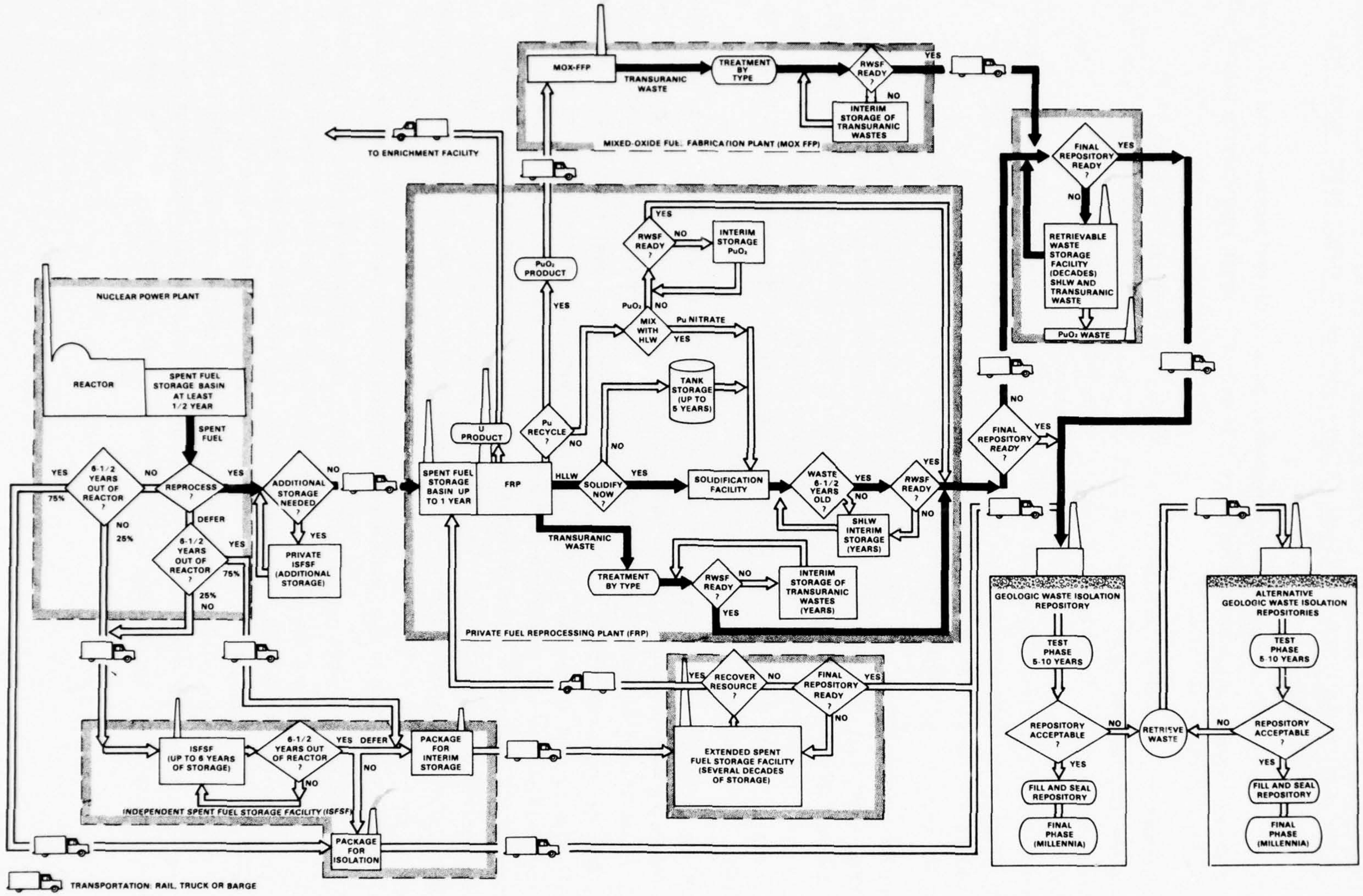

FIGURE 10.5-1. Flow of Spent Fuel and Wastes (Outlined in Black) in the Uranium and Plutonium Recycle Option with Repositories Unavailable Until Year 2000

10.5.1 Environmental Effects Related to Construction of the Integrated Waste Management System

During construction of the FRPs and MOX FFPs, waste management facilities will be built at the plant sites and RWSFs will be constructed at independent sites. Surface facilities for the repositories will be constructed along with mining of the main shaft and construction of storage rooms before waste emplacement at the repositories. Casks for waste transportation will also be constructed.

Resource Commitments

Land will be required for all surface facilities and for underground mine storage in the case of the repositories. Construction activities, roads, and railroads for access to the sites will also require land. Additional land will be needed to limit access to the facilities for security reasons.

Land use for waste management facilities will range from about 6500 to 9700 ha, depending on the number of repositories needed. This represents about 40 to 60% of the total land ($\sim$16,000 ha) required for fuel reprocessing facilities. Of the land commitment for waste management, about 4900 to 8100 are required for deep geologic repositories. The remaining 1600 ha are required for the retrievable waste storage facilities. Structures and access roads will occupy about 68 to 100 ha. The remaining land will not be used for human activities and should provide a protected terrestrial habitat. Since withdrawal of land from present use is highly site specific in terms of impact on agriculture or other uses, no further analysis of land use is made.

Water use is also highly site specific in terms of potential environmental impact. As long as water is supplied from sources such as the R River in the reference or similar environment, no significant effects, either on aquatic biota or other downstream uses, would be expected. If plants are built as described, site-specific evaluations will be required. However, because there are no unusually high demands for water for construction of individual facilities, siting for purposes of water use will probably not be a problem.

Resources committed in the construction of fuel reprocessing waste management facilities with repositories unavailable until the year 2000 are presented in Tables 10.5-1 through 10.5-4. For comparison, the table also shows resource commitments for the fuel reprocessing production facilities. For many of the resources listed in Tables 10.5-1 through 10.5-4, waste management activities require greater quantities of committed resources than the production facilities. Since this construction program will span about 50 years, these resource commitments are, however, not expected to significantly impact on other industrial needs.

No unusual transportation requirements have been identified for construction of the facilities.

Facility Effluents

The effluent of greatest concern is dust emission from the surface handling of mined material from the repositories, (discussed in Section 10.3.1). Tables 10.5-5 through 10.5-8 list

TABLE 10.5-1. Resources Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Repositories in Salt Unavailable Until the Year 2000

Resource	6.75 FRPs	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	2 RWSFs	6 Repositories	Transportation	Total for[(a)] Production Facilities	Total for[(b)] Waste Management
Land, ha									
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	3.4×10^2	1.1×10^3		3.3×10^2	1.5×10^3
Access roads and railroads	3.3×10^2	-	1.2×10^2	-	2.0×10^1	4.8×10^1		4.5×10^2	6.8×10^1
Miner and surface rights (property)	1.6×10^4	-	4.0×10^3	-	1.6×10^3	4.9×10^3		2.0×10^4	6.5×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	6.2×10^5	1.6×10^6		1.7×10^6	3.2×10^6
Materials									
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	5.2×10^5	6.6×10^5		9.2×10^5	1.7×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.1×10^5	1.1×10^5	2.3×10^3	2.3×10^5	3.5×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	6.0×10^2	1.4×10^3		1.5×10^3	3.5×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1			3.7×10^2		1.5×10^2	1.1×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		3.6×10^2	2.8×10^2		1.5×10^3	6.7×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	2.6×10^4	1.6×10^4		3.9×10^4	7.8×10^4
Lead, MT		4.4×10^2			6.4×10^2		5.2×10^3		6.2×10^3
Chromium, MT(in SS)							4.1×10^2		4.1×10^2
Nickel, MT (in SS)							1.8×10^2		1.8×10^2
Energy									
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	7.0×10^3	1.4×10^4		1.4×10^4	3.0×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	7.0×10^4	1.4×10^5		9.6×10^4	2.9×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	5.0×10^4	1.1×10^5		9.6×10^4	2.2×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	3.4×10^7	9.6×10^7		8.2×10^7	1.7×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.0×10^4	6.6×10^4		6.4×10^4	1.2×10^5

(a) Includes 6.75 FRPs and 10 MOX FFPs.

(b) Includes waste management at FRPs and MOX FFPs, RWSFs, repositories, and transportation.

TABLE 10.5-2. Resources Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Repositories in Granite Unavailable Until the Year 2000

Resource	6.75 FRPs	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	2 RWSFs	7 Repositories	Transportation	Total for[a] Production Facilities	Total for[b] Waste Management
Land, ha									
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	3.4×10^2	1.5×10^3		3.3×10^2	1.9×10^3
Access roads and railroads	3.3×10^2	-	1.2×10^2	-	2.0×10^1	5.6×10^1		4.5×10^2	7.6×10^1
Mineral and surface rights (property)	1.6×10^4	-	4.0×10^3	-	1.6×10^3	5.7×10^3		2.0×10^4	7.3×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	6.2×10^5	3.6×10^6		1.7×10^6	5.2×10^6
Materials									
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	5.2×10^5	1.5×10^6		9.2×10^5	2.6×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.1×10^5	2.3×10^5	2.3×10^3	2.3×10^5	4.7×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	6.0×10^2	3.3×10^3		1.5×10^3	5.4×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1			8.4×10^2		1.5×10^2	1.6×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		3.6×10^2	6.3×10^2		1.5×10^3	1.0×10^3
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	2.6×10^4	3.4×10^4		3.9×10^4	9.6×10^4
Lead, MT		4.4×10^2			6.4×10^2		5.2×10^3		6.2×10^3
Chromium, MT(in SS)							4.1×10^2		4.1×10^2
Nickel, MT (in SS)							1.8×10^2		1.8×10^2
Energy									
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	7.0×10^3	3.2×10^4		1.4×10^4	4.8×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	7.0×10^4	3.2×10^5		9.6×10^4	4.7×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	5.0×10^4	2.3×10^5		9.6×10^4	3.4×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	3.4×10^7	2.1×10^8		8.2×10^7	2.9×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.0×10^4	1.5×10^5		6.4×10^4	2.0×10^5

(a) Includes 6.75 FRPs and 10 MOX FFPs.

(b) Includes waste management at FRP and MOX FFPs, RWSFs, repositories, and transportation.

TABLE 10.5-3. Resources Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Repositories in Shale Unavailable Until the Year 2000

Resource	6.75 FRPs	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	2 RWSFs	10 Repositories	Transportation	Total for[a] Production Facilities	Total for[b] Waste Management
Land, ha									
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	3.4×10^2	1.8×10^3		3.3×10^2	2.2×10^3
Access roads and railroads	3.3×10^2	-	1.2×10^2	-	2.0×10^1	8.0×10^1		4.5×10^2	1.0×10^2
Mineral and surface rights (property)	1.6×10^4	-	4.0×10^3	-	1.6×10^3	8.1×10^3		2.0×10^4	9.7×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	6.2×10^5	2.9×10^6		1.7×10^6	4.5×10^6
Materials									
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	5.2×10^5	1.2×10^6		9.2×10^5	2.3×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.1×10^5	1.9×10^5	2.3×10^3	2.4×10^5	4.3×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	6.0×10^2	2.6×10^3		1.5×10^3	4.7×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1			6.7×10^2		1.5×10^2	1.4×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		3.6×10^2	5.0×10^2		1.5×10^3	8.9×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	2.6×10^4	2.8×10^4		3.9×10^4	9.0×10^4
Lead, MT		4.4×10^2			6.4×10^2		5.2×10^3		6.2×10^3
Chromium, MT(in SS)							4.1×10^2		4.1×10^2
Nickel, MT (in SS)							1.8×10^2		1.8×10^2
Energy									
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	7.0×10^3	2.6×10^4		1.4×10^4	4.2×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	7.0×10^4	2.6×10^5		9.6×10^4	4.1×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	5.0×10^4	1.9×10^5		9.6×10^4	3.0×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	3.4×10^7	1.7×10^8		8.2×10^7	2.5×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.0×10^4	1.3×10^5		6.4×10^4	1.8×10^5

(a) Includes 6.75 FRPs and 10 MOX FFPs.

(b) Includes waste management at FRP and MOX FFPs, RWSFs, repositories, and transportation.

TABLE 10.5-4. Resources Commitments Associated with Construction of Waste Management Facilities for the Integrated System in the Uranium and Plutonium Fuel Recycle Option with Repositories in Basalt Unavailable Until the Year 2000

Resource	6.75 FRPs	Waste Management at FRPs	10 MOX FFPs	Waste Management at MOX FFPs	2 RWSFs	6 Repositories	Transportation	Total for[a] Production Facilities	Total for[b] Waste Management
Land, ha									
Structures	2.7×10^2	1.3×10^2	6.0×10^1	3.4	3.4×10^2	1.3×10^3		3.3×10^2	1.7×10^3
Access roads and railroads	3.3×10^2	-	1.2×10^2	-	2.0×10^1	4.8×10^1		4.5×10^2	6.8×10^1
Mineral and surface rights (property)	1.6×10^4	-	4.0×10^3	-	1.6×10^3	4.9×10^3		2.0×10^4	6.5×10^3
Water, m^3	1.2×10^6	9.4×10^5	4.9×10^5	5.9×10^4	6.2×10^5	2.7×10^6		1.7×10^6	4.3×10^6
Materials									
Concrete, m^3	8.1×10^5	5.3×10^5	1.1×10^5	3.0×10^4	5.2×10^5	1.1×10^6		9.2×10^5	2.2×10^6
Steel, MT	1.7×10^5	1.2×10^5	6.4×10^4	6.6×10^3	1.1×10^5	1.8×10^5	2.3×10^3	2.4×10^5	4.2×10^5
Copper, MT	9.8×10^2	1.4×10^3	5.4×10^2	6.9×10^1	6.0×10^2	2.5×10^3		1.5×10^3	4.6×10^3
Zinc, MT	6.1×10^1	7.4×10^2	9.0×10^1			6.6×10^2		1.5×10^2	1.4×10^3
Aluminum, MT	1.5×10^3	3.4×10^1	4.0×10^1		3.6×10^2	4.6×10^2		1.5×10^3	8.5×10^2
Lumber, m^3	3.2×10^4	3.4×10^4	7.1×10^3	1.8×10^3	2.6×10^4	2.6×10^4		3.9×10^4	8.8×10^4
Lead, MT		4.4×10^2			6.4×10^2		5.2×10^3		6.2×10^3
Chromium, MT(in SS)							4.1×10^2		4.1×10^2
Nickel, MT (in SS)							1.8×10^2		1.8×10^2
Energy									
Propane, m^3	1.0×10^4	8.8×10^3	3.8×10^3	4.1×10^2	7.0×10^3	2.4×10^4		1.4×10^4	4.0×10^4
Diesel fuel, m^3	5.1×10^4	8.1×10^4	4.5×10^4	4.2×10^3	7.0×10^4	2.4×10^5		9.6×10^4	4.0×10^5
Gasoline, m^3	6.6×10^4	5.9×10^4	3.0×10^4	3.2×10^3	5.0×10^4	1.6×10^5		9.6×10^4	2.7×10^5
Electricity, kWh	5.0×10^7	4.3×10^7	3.2×10^7	2.8×10^6	3.4×10^7	1.6×10^8		8.2×10^7	2.4×10^8
Manpower, man-yr	4.4×10^4	4.0×10^4	2.0×10^4	1.9×10^3	1.0×10^4	1.6×10^5		6.4×10^4	2.1×10^5

(a) Includes 6.75 FRPs and 10 MOX FFPs.

(b) Includes waste management at FRP and MOX FFPs, RWSFs, repositories, and transportation.

TABLE 10.5-5. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Salt Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	2 RWSFs	6 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	3.6×10^4	5.3×10^4	1.3×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	1.4×10^3	2.4×10^3	7.5×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	4.4×10^3	1.0×10^4	1.8×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	2.6×10^2	6.0×10^2	1.1×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.4×10^4	6.0×10^2	2.2×10^4

TABLE 10.5-6. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Granite Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	2 RWSFs	7 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	3.6×10^4	1.1×10^5	6.9×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	1.4×10^3	5.2×10^3	1.0×10^4
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	4.4×10^3	2.2×10^4	3.0×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	2.6×10^2	1.3×10^3	1.8×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.4×10^4	1.3×10^3	2.3×10^4

TABLE 10.5-7. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Shale Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	2 RWSFs	10 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	3.6×10^4	9.3×10^4	1.7×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	1.4×10^3	4.2×10^3	9.3×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	4.4×10^3	1.8×10^4	2.6×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	2.6×10^2	1.1×10^3	1.6×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.4×10^4	1.1×10^3	2.2×10^4

TABLE 10.5-8. Nonradioactive Pollutants Released to the Atmosphere During Construction of the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Basalt Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	2 RWSFs	6 Repositories	Total
Carbon monoxide, MT	3.2×10^4	5.6×10^3	3.6×10^4	9.0×10^4	1.7×10^5
Hydrocarbons, MT	3.4×10^3	2.5×10^2	1.4×10^3	4.0×10^3	9.1×10^3
Nitrogen oxide, MT	3.4×10^3	1.0×10^3	4.4×10^3	1.7×10^4	2.5×10^4
Sulfur oxide, MT	1.6×10^2	6.3×10^1	2.6×10^2	1.0×10^3	1.5×10^3
Particulates, MT	5.7×10^3	1.5×10^3	1.4×10^4	1.0×10^3	2.2×10^4

the pollutants released to the atmosphere from operation of machinery on the surface and in the mines during construction of the integrated system facilities for the uranium and plutonium recycle option with repositories unavailable until the year 2000. The pollutant totals in Tables 10.5-5 through 10.5-8 do not include particulates (dust) that will be released from ground clearing. Procedures will be required to prevent the accumulation of significant quantities of fugitive dust at the site boundary. Motor vehicle emissions from the labor force traveling to and from the construction site also are not considered; however, these emissions would be spread out over such a large area and period of time (50 years) that their impact on ambient air quality concentrations should be negligible.

Ecological Effects

Ecological effects associated with construction would be expected to be substantially the same as those discussed in Section 10.1 for the once-through cycle with prompt disposal.

Accidents

Injuries and fatalities forecasted for construction of waste management facilities through the year 2050 with repositories unavailable until the year 2000 are presented in Tables 10.5-9 through 10.5-12. Injury rates of 13.6 disabling injuries per million man-hr[1] for surface construction and 25 disabling injuries per million man-hr for underground mining were used. For fatality predictions, fatality rates of 0.17 fatalities per million man-hr[1] for surface construction and 0.53 fatalities per million man-hr for underground mining were used.

The addition of 2 RWSFs for the option with repositories unavailable until the year 2000 adds <5% to the predicted injuries and fatalities compared with the prompt disposal option.

TABLE 10.5-9. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Salt Unavailable Until the Year 2000

	6.75 FRPs	10 MOX FFPs	Transportation[a]	2 RWSFs	6 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	2.8×10^2	3.0×10^3	5.0×10^3
Fatalities	1.4×10^1	1.0	5.2×10^1	4.0	6.0×10^1	1.3×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

10.5.2 Environmental Effects Related to Operation of the Integrated Waste Management System

During operation of the spent fuel reprocessing facilities radioactive wastes generated at the FRPs and MOX FFPs will be treated, stored onsite for up to 5 years, and transported to retrievable waste storage facilities pending transfer to deep geologic repositories for final isolation. Each plant will operate for 30 years and then be decommissioned. The deep geologic repositories will receive wastes for from about 8 to 20 years depending on the rate of waste generation.

TABLE 10.5-10. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Granite Unavailable Until the Year 2000

	6.75 FRPs	10 MOX FFPs	Transportation(a)	2 RWSFs	7 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	2.8×10^2	7.7×10^3	9.7×10^3
Fatalities	1.4×10^1	1.0	5.2×10^1	4.0	1.5×10^2	2.2×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

TABLE 10.5-11. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Shale Unavailable Until the Year 2000

	6.75 FRPs	10 MOX FFPs	Transportation(a)	2 RWSFs	10 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	2.8×10^2	5.9×10^3	7.9×10^3
Fatalities	1.1×10^1	1.0	5.2×10^1	4.0	1.2×10^2	1.9×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

TABLE 10.5-12. Nonradiological Injuries and Fatalities Associated with Construction of Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Basalt Unavailable Until the Year 2000

	6.75 FRPs	10 MOX FFPs	Transportation(a)	2 RWSFs	6 Repositories	Total
Injuries	1.1×10^3	5.2×10^1	5.0×10^2	2.8×10^2	7.8×10^3	9.8×10^3
Fatalities	1.1×10^1	1.0	5.2×10^1	4.0	1.6×10^2	2.3×10^2

a. Driver injuries and fatalities due to transportation accidents (rail and truck).

Resource Commitments

Materials and energy requirements for operation (1980 to 2050) of the waste management facilities associated with uranium and plutonium recycle with repositories unavailable until the year 2000 are given in Tables 10.5-13 through 10.5-16. Annual requirements for cooling and process water are given in Table 10.3-19 (Section 10.3.2). Because water resources are replenished annually, water use is given in annual terms rather than in total.

Annual water use for the waste management facilities is a small fraction of that used in the production facilities. The impact of water use is highly site specific and a detailed analysis of impacts on water sources would be required if and when such facilities are planned. As long as water can be obtained from sources such as the R River, the demands for water for waste management can be easily met.

TABLE 10.5-13. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Repositories in Salt Unavailable Until the Year 2000

Resource	6.75 FRPs	10 MOX FFPS	Transportation	2 RWSFs	6 Repositories	Total
Materials						
Steel, MT				1.4×10^5	4.9×10^5	6.3×10^5
Concrete, MT				2.9×10^4	4.4×10^5	4.7×10^5
Lime, MT		1.9×10^3				1.9×10^3
Acetylene	1.0×10^2	1.5×10^1				1.2×10^2
Stainless Steel, MT	4.5×10^4					4.5×10^4
CaO, MT	2.8×10^2					2.8×10^2
Gas cylinders	3.0×10^4					3.0×10^4
Frit, MT	5.1×10^4					5.1×10^4
Sand, MT	1.3×10^5					1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5				3.3×10^5
Caustic, m^3	1.6×10^3					1.6×10^3
HNO_3, m^3	2.4×10^3					2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3				1.1×10^4
NH_3, MT	2.8×10^4					2.8×10^4
Argon, m^3	1.8×10^6					1.8×10^6
Helium, m^3	1.4×10^5					1.4×10^5
Liquid nitrogen, m^3	8.1×10^4					8.1×10^4
Silver zeolite, m^3	4.3×10^3					4.3×10^3
Silica gel, m^3	1.0×10^2					1.0×10^2
Detergent, MT	1.1×10^2					1.1×10^2
55-gal drums	1.2×10^6					1.2×10^6
Waste canisters						
0.76 x 3.05 m	9.7×10^4					9.7×10^4
0.3 x 3 m	1.3×10^5					1.3×10^5
Cardboard boxes						
30 x 30 x 60 cm	2.0×10^6	1.4×10^5				2.1×10^6
Plastic sheets, m^2	1.3×10^5			1.2×10^5		2.5×10^5
Filters	6.5×10^4					6.5×10^4
Plywood, m^2	6.9×10^5			4.0×10^5		1.1×10^6
Utilities						
Water consumed, m^3	8.9×10^7	2.5×10^5		1.2×10^4	-	8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.9×10^9	1.3×10^{10}	3.3×10^{10}
Steam, MT	-	-			9.0×10^7	9.0×10^7
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	2.9×10^4	1.5×10^6	2.8×10^6
Propane, m^3	2.0×10^7	3.0×10^6				2.3×10^7
Oil, m^3	7.7×10^4	-				7.7×10^4
Coal, MT	-	-			8.4×10^6	8.4×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		3.5×10^3	1.1×10^5	1.4×10^5

TABLE 10.5-14. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Repositories in Granite Unavailable Until the Year 2000

Resource	6.75 FRPs	10 MOX FFPS	Transportation	2 RWSFs	7 Repositories	Total
Materials						
Steel, MT				1.4×10^5	1.7×10^6	1.8×10^6
Concrete, MT				2.9×10^4	5.1×10^5	5.4×10^5
Lime, MT		1.9×10^3				1.9×10^3
Acetylene	1.0×10^2	1.5×10^1				1.2×10^2
Stainless Steel, MT	4.5×10^4					4.5×10^4
CaO, MT	2.8×10^2					2.8×10^2
Gas cylinders	3.0×10^4					3.0×10^4
Frit, MT	5.1×10^4					5.1×10^4
Sand, MT	1.3×10^5					1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5				3.3×10^5
Caustic, m^3	1.6×10^3					1.6×10^3
HNO_3, m^3	2.4×10^3					2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3				1.1×10^4
NH_3, MT	2.8×10^4					2.8×10^4
Argon, m^3	1.8×10^6					1.8×10^6
Helium, m^3	1.4×10^5					1.4×10^5
Liquid nitrogen, m^3	8.1×10^4					8.1×10^4
Silver zeolite, m^3	4.3×10^3					4.3×10^3
Silica gel, m^3	1.0×10^2					1.0×10^2
Detergent, MT	1.1×10^2					1.1×10^2
55-gal drums	1.2×10^6					1.2×10^6
Waste canisters						
0.76 x 3.05 m	9.7×10^4					9.7×10^4
0.3 x 3 m	1.3×10^5					1.3×10^5
Cardboard boxes						
30 x 30 x 60 cm	2.0×10^6	1.4×10^5				2.1×10^6
Plastic sheets, m^2	1.3×10^5			1.2×10^5		2.5×10^5
Filters	6.5×10^4					6.5×10^4
Plywood, m^2	6.9×10^5			4.0×10^5		1.1×10^6
Utilities						
Water consumed, m^3	8.9×10^7	2.5×10^5		1.2×10^4	-	8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.9×10^9	1.8×10^{10}	3.8×10^{10}
Steam, MT	-	-			1.1×10^8	1.1×10^8
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	2.9×10^4	1.8×10^6	3.1×10^6
Propane, m^3	2.0×10^7	3.0×10^6				2.3×10^7
Oil, m^3	7.7×10^4	-				7.7×10^4
Coal, MT	-	-			9.8×10^6	9.8×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		3.5×10^3	1.7×10^5	2.1×10^5

TABLE 10.5-15. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Repositories in Shale Unavailable Until the Year 2000

Resource	6.75 FRPs	10 MOX FFPS	Transportation	2 RWSFs	10 Repositories	Total
Materials						
Steel, MT				1.4×10^5	6.0×10^5	7.4×10^5
Concrete, MT				2.9×10^4	7.3×10^5	7.6×10^5
Lime, MT		1.9×10^3				1.9×10^3
Acetylene	1.0×10^2	1.5×10^1				1.2×10^2
Stainless Steel, MT	4.5×10^4					4.5×10^4
CaO, MT	2.8×10^2					2.8×10^2
Gas cylinders	3.0×10^4					3.0×10^4
Frit, MT	5.1×10^4					5.1×10^4
Sand, MT	1.3×10^5					1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5				3.3×10^5
Caustic, m^3	1.6×10^3					1.6×10^3
HNO_3, m^3	2.4×10^3					2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3				1.1×10^4
NH_3, MT	2.8×10^4					2.8×10^4
Argon, m^3	1.8×10^6					1.8×10^6
Helium, m^3	1.4×10^5					1.4×10^5
Liquid nitrogen, m^3	8.1×10^4					8.1×10^4
Silver zeolite, m^3	4.3×10^3					4.3×10^3
Silica gel, m^3	1.0×10^2					1.0×10^2
Detergent, MT	1.1×10^2					1.1×10^2
55-gal drums	1.2×10^6					1.2×10^6
Waste canisters						
0.76 x 3.05 m	9.7×10^4					9.7×10^4
0.3 x 3 m	1.3×10^5					1.3×10^5
Cardboard boxes						
30 x 30 x 60 cm	2.0×10^6	1.4×10^5				2.1×10^6
Plastic sheets, m^3	1.3×10^5			1.2×10^5		2.5×10^5
Filters	6.5×10^4					6.5×10^4
Plywood, m^2	6.9×10^5			4.0×10^5		1.1×10^6
Utilities						
Water consumer, m^3	8.9×10^7	2.5×10^5		1.2×10^4	-	8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.9×10^9	1.4×10^{10}	3.4×10^{10}
Steam, MT	-	-			1.0×10^8	1.0×10^8
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	2.9×10^4	1.7×10^6	3.0×10^6
Propane, m^3	2.0×10^7	3.0×10^6			-	2.3×10^7
Oil, m^3	7.7×10^4	-			-	7.7×10^4
Coal, MT	-	-			9.4×10^6	9.4×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		3.5×10^3	1.3×10^5	1.6×10^5

TABLE 10.5-16. Material and Utility Commitments Associated with Operation of the Integrated Waste Management System Facilities Through the Year 2050 for the Uranium and Plutonium Recycle Option with Repositories in Basalt Unavailable Until the Year 2000

Resource	6.75 FRPs	10 MOX FFPS	Transportation	2 RWSFs	6 Repositories	Total
Materials						
Steel, MT				1.4×10^5	1.3×10^6	1.4×10^6
Concrete, MT				2.9×10^4	4.4×10^5	4.7×10^5
Lime, MT		1.9×10^3				1.9×10^3
Acetylene	1.0×10^2	1.5×10^1				1.2×10^2
Stainless Steel, MT	4.5×10^4					4.5×10^4
CaO, MT	2.8×10^2					2.8×10^2
Gas cylinders	3.0×10^4					3.0×10^4
Frit, MT	5.1×10^4					5.1×10^4
Sand, MT	1.3×10^5					1.3×10^5
Cement, MT	2.2×10^5	1.1×10^5				3.3×10^5
Caustic, m^3	1.6×10^3					1.6×10^3
HNO_3, m^3	2.4×10^3					2.4×10^3
NaOH, MT	1.0×10^4	1.1×10^3				1.1×10^4
NH_3, MT	2.8×10^4					2.8×10^4
Argon, m^3	1.8×10^6					1.8×10^6
Helium, m^3	1.4×10^5					1.4×10^5
Liquid nitrogen, m^3	8.1×10^4					8.1×10^4
Silver zeolite, m^3	4.3×10^3					4.3×10^3
Silica gel, m^3	1.0×10^2					1.0×10^2
Detergent, MT	1.1×10^2					1.1×10^2
55-gal drums	1.2×10^6					1.2×10^6
Waste canisters						
0.76 x 3.05 m	9.7×10^4					9.7×10^4
0.3 x 3 m	1.3×10^5					1.3×10^5
Cardboard boxes						
30 x 30 x 60 cm	2.0×10^6	1.4×10^5				2.1×10^6
Plastic sheets, m^2	1.3×10^5			1.2×10^5		2.5×10^5
Filters	6.5×10^4					6.5×10^4
Plywood, m^2	6.9×10^5			4.0×10^5		1.1×10^6
Utilities						
Water consumed, m^3	8.9×10^7	2.5×10^5		1.2×10^4		8.9×10^7
Electricity, kWh	1.8×10^{10}	4.2×10^8		1.9×10^9	-	3.4×10^{10}
Steam, MT	-	-			8.4×10^7	8.4×10^7
Diesel fuel, m^3	4.9×10^3	1.6×10^4	1.3×10^6	2.9×10^4	1.4×10^6	2.7×10^6
Propane, m^3	2.0×10^7	3.0×10^6			-	2.3×10^7
Oil, m^3	7.7×10^4	-			-	7.7×10^4
Coal, MT	-	-			7.8×10^6	7.8×10^6
Manpower, man-yr	3.0×10^4	2.6×10^3		3.5×10^3	1.3×10^5	1.6×10^5

In terms of energy requirements, the equivalent of about 0.1% of the electricity produced in the reference nuclear power plants through the year 2050 will be required for operating the various waste management facilities. All electricity uses are not accounted for in the total given in Tables 10.5-13 through 10.5-16. It is believed, however, that use of electricity in the formation of resource materials will not add significantly to the total electricity used. For example, for either aluminum or cement, which are relatively energy intensive in their formation, about 8×10^7 kWh are required. This requirement would not add significantly to the 3×10^{10} kWh required for operating facilities.

Diesel fuel consumed through the year 2050 in support of waste management activities will be $2.7\text{-}3.1 \times 10^6$ m^3. Over the same 70-year period, the amount of diesel fuel used in the United States, if used at a rate of 4×10^7 m^3/yr (nominal annual rate for 1972 to 1975), will amount to about 7.8×10^8 m^3. Thus, diesel fuel consumption in support of waste management activities would add about 0.4% to the existing U.S. requirements.

The use of propane for incineration of combustible wastes through the year 2050 was estimated at 2.3×10^7 m^3. The average annual use of propane in the United States (1973 to 1975) was about 3.7×10^7 m^3. If this use rate continued over the 70-year period ending in 2050, the total U.S. requirement for propane would be 2.6×10^9 m^3. Thus, propane required in waste management would result in an approximately 0.9% increase in the U.S. requirements over that period. No significant increases were noted for long-term storage of waste or the RWSFs.

Process Effluents

The major nonradioactive effluent released from the integrated system at repositories in salt would be salt dust. Other nonradioactive pollutants released to the biosphere during the operational life of the facilities are given in Tables 10.5-17 through 10.5-20.

TABLE 10.5-17. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option with Repositories in Salt Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	6 Repositories	Total
Hydrogen chloride, MT	3.4×10^1	2.4	-	-		3.6×10^1
Carbon monoxide, MT	6.1×10^1	5.1	4.6×10^4	2.0×10^2	1.7×10^4	6.3×10^4
Nitrogen oxide, MT	2.8×10^2	9.9	8.5×10^4	4.0	1.0×10^5	1.8×10^5
Sulfur oxide, MT	6.1×10^1	4.5	7.9×10^3	2.0	7.2×10^4	8.0×10^4
Particulates, MT	1.0×10^2	1.1×10^1	3.8×10^3	8.0	3.1×10^3	6.9×10^3
Ammonia, MT	2.0×10^3					2.0×10^3
Argon, MT	2.4×10^3					2.4×10^3
Organic acids, MT			3.9×10^2			3.9×10^2
Aldehydes, MT			3.0×10^2			3.0×10^2
Hydrocarbons, MT			1.2×10^4	8.0×10^{-1}	6.0×10^3	1.8×10^4
Nitrogen, MT	2.4×10^5					2.4×10^5
Oxygen, MT	1.5×10^5					1.5×10^5
Hydrogen, MT	1.6×10^2					1.6×10^2
Helium, MT	2.0×10^1					2.0×10^1
Heat, MJ	8.1×10^{11}	2.9×10^{10}			4.6×10^9	8.4×10^{11}

TABLE 10.5-18. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option with Repositories in Granite Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	7 Repositories	Total
Hydrogen chloride, MT	3.4×10^1	2.4	-		-	3.6×10^1
Carbon monoxide, MT	6.1×10^1	5.1	4.6×10^4	2.0×10^2	2.1×10^4	6.7×10^4
Nitrogen oxide, MT	2.8×10^2	9.9	8.5×10^4	4.0	1.3×10^5	2.2×10^5
Sulfur oxide, MT	6.1×10^1	4.5	7.9×10^3	2.0	8.4×10^4	9.2×10^4
Particulates, MT	1.0×10^2	1.1×10^1	3.8×10^3	8.0	3.8×10^3	7.7×10^3
Ammonia, MT	2.0×10^3					2.0×10^3
Argon, MT	2.4×10^3					2.4×10^3
Organic acids, MT	-		3.9×10^2			3.9×10^2
Aldehydes, MT	-		3.0×10^2			3.0×10^2
Hydrocarbons, MT	-		1.2×10^4	8.0×10^{-1}	7.7×10^3	2.0×10^4
Nitrogen, MT	2.4×10^5					2.4×10^5
Oxygen, MT	1.5×10^5					1.5×10^5
Hydrogen, MT	1.6×10^2					1.6×10^2
Helium, MT	2.0×10^1					2.0×10^1
Heat, MJ	8.1×10^{11}	2.9×10^{10}			5.8×10^9	8.4×10^{11}

TABLE 10.5-19. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option with Repositories in Shale Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	10 Repositories	Total
Hydrogen chloride, MT	3.4×10^1	2.4				3.6×10^1
Carbon monoxide, MT	6.1×10^1	5.1	4.6×10^4	2.0×10^2	2.0×10^4	6.6×10^4
Nitrogen oxide, MT	2.8×10^2	9.9	8.5×10^4	4.0	1.2×10^5	2.1×10^5
Sulfur oxide, MT	6.1×10^1	4.5	7.9×10^3	2.0	7.8×10^4	8.6×10^4
Particulates, MT	1.0×10^2	1.1×10^1	3.8×10^3	8.0	3.5×10^3	7.4×10^3
Ammonia, MT	2.0×10^3					2.0×10^3
Argon, MT	2.4×10^3					2.4×10^3
Organic acids, MT	-		3.9×10^2			3.9×10^2
Aldehydes, MT	-		3.0×10^2			3.0×10^2
Hydrocarbons, MT	-		1.2×10^4	8.0×10^{-1}	7.1×10^3	1.9×10^4
Nitrogen, MT	2.4×10^5					2.4×10^5
Oxygen, MT	1.5×10^5					1.5×10^5
Hydrogen, MT	1.6×10^2					1.6×10^2
Helium, MT	2.0×10^1					2.0×10^1
Heat, MJ	8.1×10^{11}	2.9×10^{10}			4.3×10^9	8.4×10^{11}

TABLE 10.5-20. Nonradioactive Pollutants Associated with Integrated Production and Waste Management System Facilities Through 2050 for the Uranium and Plutonium Recycle Option with Repositories in Basalt Unavailable Until the Year 2000

Pollutant	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	6 Repositories	Total
Hydrogen chloride, MT	3.4×10^1	2.4				3.6×10^1
Carbon monoxide, MT	6.1×10^1	5.1	4.6×10^4	2.0×10^2	1.6×10^4	6.2×10^4
Nitrogen oxide, MT	2.8×10^2	9.9	8.5×10^4	4.0	1.0×10^5	1.8×10^5
Sulfur oxide, MT	6.1×10^1	4.5	7.9×10^3	2.0	6.6×10^4	7.4×10^4
Particulates, MT	1.0×10^2	1.1×10^1	3.8×10^3	8.0	2.9×10^3	6.7×10^3
Ammonia, MT	2.0×10^3					2.0×10^3
Argon, MT	2.4×10^3					2.4×10^3
Organic acids, MT	-		3.9×10^2			3.9×10^2
Aldehydes, MT	-		3.0×10^2			3.0×10^2
Hydrocarbons, MT	-		1.2×10^4	8.0×10^{-1}	5.9×10^3	1.8×10^4
Nitrogen, MT	2.4×10^5					2.4×10^5
Oxygen, MT	1.5×10^5					1.5×10^5
Hydrogen, MT	1.6×10^2					1.6×10^2
Helium, MT	2.0×10^1					2.0×10^1
Heat, MJ	8.1×10^{11}	2.9×10^{10}			4.2×10^9	8.4×10^{11}

Routine releases of radioactive material from all the facilities will consist of naturally occurring radon and its decay products from the repository and radionuclides released during operation of the FRPs and MOX FFPs. Direct radiation will emanate from wastes during transport from one facility to another. Radionuclides released to the biosphere are listed in Tables 10.5-21 through 10.5-24.

Physical, Chemical, and Thermal Effects

Atmospheric effects resulting from operations of these facilities would include air quality impacts resulting from emission of nonradioactive pollutants, release of sensible heat, and emission of fugitive salt from material excavated from the repository.

Potentially, the greatest effect would be from the salt dust emissions from excavated materials. Although the largest removal of salt occurs during the operational phase of a waste repository in salt, the postulated salt depositions that would result from the total mined material were discussed under construction impacts in Section 10.5.1.

Heat rejection from rail and truck shipments of waste would be several orders of magnitude less than a heat load from a stationary facility, which is considered to have only microclimatic effects; as a consequence, no significant atmospheric effects are postulated. Both the heat loads and combustion product releases from shipments of wastes would amount to a small increment over total present releases associated with rail and truck transport.

TABLE 10.5-21. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option 1980-2050 - with Repositories in Salt Unavailable Until the Year 2000, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	2 RWSFs	6 Repositories	Total
^{3}H	1.5×10^{8}				1.5×10^{8}
^{14}C	1.4×10^{6}				1.4×10^{6}
^{85}Kr	3.4×10^{8}				3.4×10^{8}
^{90}Sr	1.1×10^{-2}		3.9×10^{-10}		1.1×10^{-2}
^{106}Ru	1.5×10^{3}				1.5×10^{3}
^{129}I	4.5×10^{1}				4.5×10^{1}
^{137}Cs	1.6×10^{-2}		6.0×10^{-11}		1.6×10^{-2}
^{210}Pb				7.8×10^{-7}	7.8×10^{-7}
^{210}Bi				9.6×10^{-3}	9.6×10^{-3}
^{212}Pb				1.0×10^{-5}	1.0×10^{-5}
^{214}Pb				9.6×10^{-3}	9.6×10^{-3}
^{220}Rn				6.6×10^{-3}	6.6×10^{-3}
^{222}Rn				9.6×10^{-3}	9.6×10^{-3}
^{236}U	1.1				1.1
^{238}U	1.3				1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}			7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}	1.4×10^{-14}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}			1.1×10^{-2}
^{241}Pu	1.5	1.1			2.6
^{241}Am		8.7×10^{-1}	2.2×10^{-11}		8.7×10^{-1}

TABLE 10.5-22. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option 1980-2050 - with Repositories in Granite Unavailable Until the Year 2000, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	2 RWSFs	7 Repositories	Total
^{3}H	1.5×10^{8}				1.5×10^{8}
^{14}C	1.4×10^{6}				1.4×10^{6}
^{85}Kr	3.4×10^{8}				3.4×10^{8}
^{90}Sr	1.1×10^{-2}		3.9×10^{-10}		1.1×10^{-2}
^{106}Ru	1.5×10^{3}				1.5×10^{3}
^{129}I	4.5×10^{1}				4.5×10^{1}
^{137}Cs	1.6×10^{-2}		6.0×10^{-11}		1.6×10^{-2}
^{210}Pb				7.7×10^{-3}	7.7×10^{-3}
^{210}Bi				9.1×10^{1}	9.1×10^{1}
^{212}Pb				1.5×10^{-1}	1.5×10^{-1}
^{214}Pb				9.1×10^{1}	9.1×10^{1}
^{220}Rn				9.8×10^{1}	9.8×10^{1}
^{222}Rn				9.1×10^{1}	9.1×10^{1}
^{236}U	1.1				1.1
^{238}U	1.3				1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}			7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}	1.4×10^{-14}		7.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}			1.1×10^{-2}
^{241}Pu	1.5	1.1			2.6
^{241}Am		8.7×10^{-1}	2.2×10^{-11}		8.7×10^{-1}

TABLE 10.5-23. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option 1980-2050 - with Repositories in Shale Unavailable Until the Year 2000, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	2 RWSFs	10 Repositories	Total
^{3}H	1.5×10^{8}				1.5×10^{8}
^{14}C	1.4×10^{6}				1.4×10^{6}
^{85}Kr	3.4×10^{8}				3.4×10^{8}
^{90}Sr	1.1×10^{-2}		3.9×10^{-10}		1.1×10^{-2}
^{106}Ru	1.5×10^{3}				1.5×10^{3}
^{129}I	4.5×10^{1}				4.5×10^{1}
^{137}Cs	1.6×10^{-2}		6.0×10^{-11}		1.6×10^{-2}
^{210}Pb				2.5×10^{-3}	2.5×10^{-3}
^{210}Bi				6.0×10^{1}	6.0×10^{1}
^{212}Pb				7.7×10^{-2}	7.7×10^{-2}
^{214}Pb				6.0×10^{1}	6.0×10^{1}
^{220}Rn				5.1×10^{1}	5.1×10^{1}
^{222}Rn				6.0×10^{1}	6.0×10^{1}
^{236}U	1.1				1.1
^{238}U	1.3				1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}			7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}	1.4×10^{-14}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}			1.1×10^{-2}
^{241}Pu	1.5	1.1			2.6
^{241}Am		8.7×10^{-1}	2.2×10^{-11}		8.7×10^{-1}

TABLE 10.5-24. Radionuclides Released to the Atmosphere from Production and Waste Management System Facilities for the Uranium and Plutonium Recycle Option 1980-2050 - with Repositories in Basalt Unavailable Until the Year 2000, Ci

Radionuclide	6.75 FRPs	10 MOX FFPs	2 RWSFs	6 Repositories	Total
^{3}H	1.5×10^{8}				1.5×10^{8}
^{14}C	1.4×10^{6}				1.4×10^{6}
^{85}Kr	3.4×10^{8}				3.4×10^{8}
^{90}Sr	1.1×10^{-2}		3.9×10^{-10}		1.1×10^{-2}
^{106}Ru	1.5×10^{3}				1.5×10^{3}
^{129}I	4.5×10^{1}				4.5×10^{1}
^{137}Cs	1.6×10^{-2}		6.0×10^{-11}		1.6×10^{-2}
^{210}Pb				8.4×10^{-4}	8.4×10^{-4}
^{210}Bi				1.0×10^{1}	1.0×10^{1}
^{212}Pb				1.8×10^{-2}	1.8×10^{-2}
^{214}Pb				1.0×10^{1}	1.0×10^{1}
^{220}Rn				1.2×10^{1}	1.2×10^{1}
^{222}Rn				1.0×10^{1}	1.0×10^{1}
^{236}U	1.1				1.1
^{238}U	1.3				1.3
^{238}Pu	4.5×10^{-2}	3.3×10^{-2}			7.8×10^{-2}
^{239}Pu	2.4×10^{-3}	2.2×10^{-3}	1.4×10^{-14}		4.6×10^{-3}
^{240}Pu	5.9×10^{-3}	4.8×10^{-3}			1.1×10^{-2}
^{241}Pu	1.5	1.1			2.6
^{241}Am		8.7×10^{-1}	2.2×10^{-11}		8.7×10^{-1}

Table 10.5-25 lists the concentrations of nonradioactive pollutants (e.g., combustion products in the atmosphere) at the facility fenceline from burning diesel fuel and chemicals. These concentrations are all less than federal ambient air quality standards and no significant ecological effects are expected.

TABLE 10.5-25. Average Atmospheric Concentrations of Nonradioactive Pollutants Released During Operation of Individual Facilities for the Uranium and Plutonium Recycle Option, 1980-2050, μg/m³

Pollutant	FRP	MOX FFP	RWSF	Repository[(a)]	Air Quality Standard
Nitrogen oxides	0.025	<0.001	0.005	8.4	1.0×10^{2} (b,d)
Carbon monoxide	0.001	<0.001	0.22	1.0	4×10^{4} (b,d)
Sulfur oxide	<0.001	<0.001	<0.001	2.5	8.0×10^{1} (b,e)
Ammonia	0.2				1.8×10^{4} (c)
Hydrochloric acid	<0.001	<0.001			7.0×10^{3} (c)
Argon	0.007				1.5×10^{7} (b)
Nitrogen	0.5				8.7×10^{8} (b)
Oxygen	0.3				2.7×10^{8} (b)
Hydrogen	<0.001				4.0×10^{1} (b)
Helium	<0.001				
Particulates	<0.001	<0.001	0.001	0.6	7.5×10^{1} (a)
Hydrocarbons			0.002		1.6×10^{2} (b)

a. Air concentrations are expected to be approximately equal for repositories in the four geologic media.
b. A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.[(2)]
c. Threshold Limit Values for Current Year (1976), American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.[(3)]
d. One hour average not to be exceeded more than once per year.
e. Annual average never to be exceeded, i.e., annual geometric mean.

The atmospheric effects, visible plume lengths, and drift deposition caused by heat rejection associated with waste management activities from the FRP and MOX FFP cooling towers will be insignificant. Temperature elevations from FRP production and from waste management activities will be less than 0.5°C at 1 km downwind and less than a few tenths of a degree at distances beyond 1.6 km. The impacts of water use during plant operation are highly site specific. However, as long as sources such as the R River in the reference environment are used, no effects on aquatic biota would be expected from withdrawal of water or from the discharge of chemicals and heat from process cooling systems.

Radiological Effects

Radiation doses in the vicinity of the facilities during normal operation for the uranium and plutonium recycle option with repositories unavailable until the year 2000 were calculated based on the radioactive releases listed in Tables 10.5-21 through 10.5-24. These doses were

based on releases from mining operations, reprocessing and fuel fabrication operations, and transportation of waste from FRPs and MOX FFPs to geologic repositories. The only exposure pathway to man and to the environment is via airborne effluents, since there are no planned releases to ground or water. Normal releases from the repositories are naturally occurring radon and its decay products liberated from mined material. Release/dose factors and dose by 5-year intervals are presented in Appendix D.

Seventy-year doses from all pathways to the population within 80 km, to the worldwide population, and to the work force are given in Tables 10.5-26 through 10.5-29.

For the period of analysis, 1980 to 2050, about three to 24 radiation-related health effects would result from the total regional man-rem dose, assuming 100 to 800 health effects per million man-rem. For the worldwide population, 110 to 900 such health effects were estimated.

TABLE 10.5-26. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Salt Unavailable Until the Year 2000, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	6 Repositories	Total	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.8×10^1	9.3×10^2	0	5.1×10^{-2}	2.5×10^4	$1.4 \times 10^{7(a)}$
Worldwide Population	1.1×10^6	0	0	0	0	1.1×10^6	4.6×10^{10}
Work Force	9.5×10^4	2.7×10^4	4.8×10^4	7.2×10^3	3.6×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

TABLE 10.5-27. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Granite Unavailable Until the Year 2000, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	7 Repositories	Total	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.8×10^1	9.3×10^2	0	4.8×10^2	2.5×10^4	$1.4 \times 10^{7(a)}$
Worldwide Population	1.1×10^6	0	0	0	0	1.1×10^6	4.6×10^{10}
Work Force	9.5×10^4	2.7×10^4	4.8×10^4	7.2×10^3	3.6×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

TABLE 10.5-28. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Shale Unavailable Until the Year 2000, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	10 Repositories	Total	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.8×10^1	9.3×10^2	0	3.2×10^2	2.5×10^4	1.4×10^{7}(a)
Worldwide Population	1.1×10^6	0	0	0	0	1.1×10^6	4.6×10^{10}
Work Force	9.5×10^4	2.7×10^4	4.8×10^4	7.2×10^3	3.6×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

TABLE 10.5-29. 70-Year Total-Body Doses from the Integrated Waste Management System Facilities for the Uranium and Plutonium Recycle Option with Repositories in Basalt Unavailable Until the Year 2000, man-rem

	6.75 FRPs	10 MOX FFPs	Transportation	2 RWSFs	6 Repositories	Total	Dose from Naturally Occurring Sources
Regional Population	2.4×10^4	1.8×10^1	9.3×10^2	0	5.5×10^1	2.5×10^4	1.4×10^{7}(a)
Worldwide Population	1.1×10^6	0	0	0	0	1.1×10^6	4.6×10^{10}
Work Force	9.5×10^4	2.7×10^4	4.8×10^4	7.2×10^3	3.6×10^4	2.1×10^5	

a. Assumes that all facilities are colocated.

Ecological Effects

The major adverse ecological impacts from uranium and plutonium fuel recycle, whether delayed or not, are believed to be, as in the case of the once-through cycle, the deposition of salt associated with construction and operation of the reference deep geologic repository in salt. This problem is not likely to be insurmountable; however, careful attention will need to be paid to the movement and storage of salt at such time as specific facilities are constructed. The effects to be expected from salt handling are treated in Section 10.1.1. Deposition of nonradioactive pollutants from ventilation and machinery operation would be well below the threshold of environmental effects.

Impacts on the terrestrial environments from effluents other than salt dust will be limited to cooling tower drift. Modern cooling towers exhibit very small fractions of circulating cooling water (0.0001 and below) as drift. Deposition of drift-derived salts from radioactive waste management is believed to be insignificant. In terms of thermal impact, the temperature increases beyond site boundaries will be only a few tenths of a degree. Thus, planned heat releases are not expected to have any adverse effect on terrestrial ecosystems.

A significant beneficial impact on terrestrial biota will be the reduction in human activity as a result of security requirements in restricted areas at waste management facilities. These conditions should provide for a substantial increase in relatively undisturbed terrestrial habitat.

Water use at the waste management facilities where water is taken from sources such as the R River in the reference or similar environment should have no significant impact on aquatic ecosystems.

Accidents

For the uranium and plutonium recycle option, shipments of waste will include rail transport of solidified high-level waste and fuel residues as well as truck transport of non-high-level transuranic waste. For the analysis period of 1980 to 2050, travel between the facilities (FRPs and MOX FFPs) and the repositories would involve an estimated 212 million railcar km and 912 million truck km. The estimated number of nonradiological fatalities would be 50, based on 0.039 fatalities per million km of rail transport and 0.045 fatalities per million km of truck transport. Nonradiological disabling injuries were estimated to be 400 for the 70-year analysis period.

There appears to be no important difference in terms of environmental effects associated with prompt or delayed disposal of wastes from fuel reprocessing; most effects result from FRP operation and repository construction with insignificant addition from 2 RWSFs.

REFERENCES FOR SECTION 10.5

1. Accident Facts, National Safety Council, Chicago, IL, 1974.

2 A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, NY, 1973.

3. Threshold Limit Values for Current Year (1976), American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.

10.6 <u>ENVIRONMENTAL EFFECTS RELATED TO THE INTEGRATED WASTE MANAGEMENT SYSTEM FACILITIES FOR THE URANIUM ONLY RECYCLE OPTION</u>

10.6 ENVIRONMENTAL EFFECTS RELATED TO THE INTEGRATED WASTE MANAGEMENT SYSTEM FACILITIES FOR THE URANIUM ONLY RECYCLE OPTION

In the uranium-only recycle option, spent fuel from reactors is moved to the reactor spent fuel storage basin for one-half year and then transferred to the receiving basin at the FRP, where it remains an additional year. The fuel is then dissolved and the uranium is recovered and sent to an enrichment plant to re-enter the fuel cycle. Plutonium is also separated and is either mixed with the solidified high-level waste or stored as the oxide. High-level waste is solidified by vitrification and stored until the time out of the reactor reaches 6-1/2 years, at which time it is sent to a deep geologic waste repository. Fuel residues and transuranic wastes are also sent to the deep geologic repository. For storage of plutonium as the oxide, proper spacing to be used in the deep geologic waste repository has not been determined. The plutonium oxide will be sent to a retrievable waste storage facility until it can be sent to isolation.

Waste flow for uranium recycle with plutonium stored in solidified high-level waste is shown in Figure 10.6-1 and with plutonium stored as the oxide in Figure 10.6-2.

Plants and/or functions for which management of radioactive wastes are considered in the uranium recycle option with plutonium in solidified high-level waste are (in order of time out of the reactor):

- treatment of radioactive gaseous effluents at the FRP
- onplant interim storage of solidified high-level wastes, transuranic wastes, and ^{85}Kr
- transport of solidified high-level wastes, fuel residues, and transuranic wastes to a geologic repository.

Plants and/or functions for which management of radioactive wastes are considered for the uranium recycle option with plutonium stored as oxide are the same as those for storage in solidified high-level waste with the following additions:

- onplant interim storage of plutonium oxide
- truck transport of plutonium oxide to a retrievable waste storage facility.

There are not many differences between waste management associated with uranium-only recycle and uranium and plutonium recycle. In most instances doses calculated vary by less than 25%, which is hardly significant. The main difference, from an environmental standpoint, occurs in the case where plutonium oxide is stored at a retrievable waste storage facility. (The reference scenario does not include isolation of plutonium oxide in the geologic repository.) In the case of storage of plutonium oxide, seventeen 200-MT plutonium oxide storage facilities would be required for indefinite storage of plutonium. Resource commitments for these facilities are given in Table 10.6-1.

Resources committed to the fabrication of shipping casks for transport of waste plutonium oxide are given in Table 10.6-2.

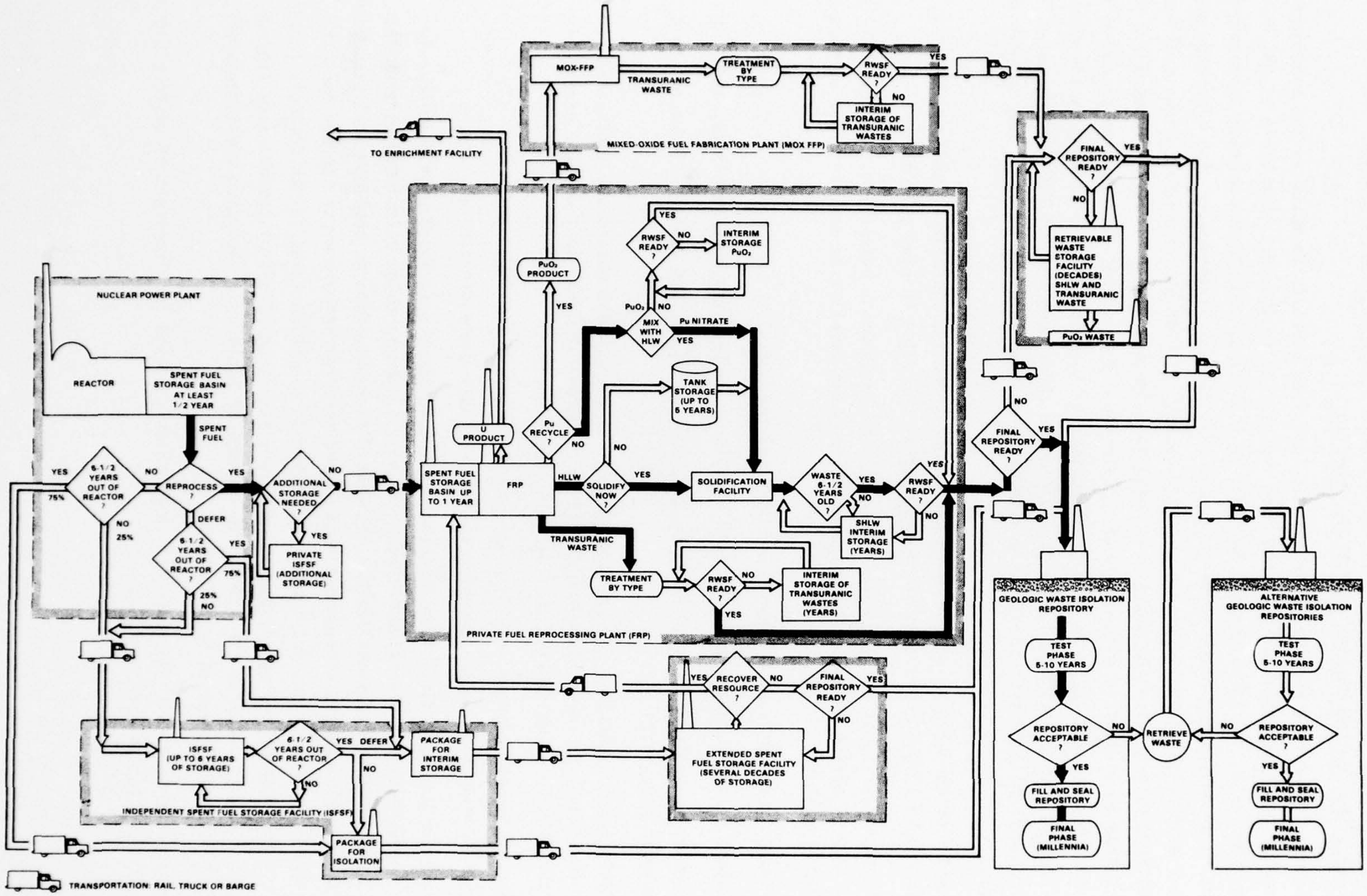

FIGURE 10.6-1. Flow of Spent Fuel and Wastes (Outlined in Black) in the Uranium Recycle Option with Plutonium in Solidified High-Level Waste

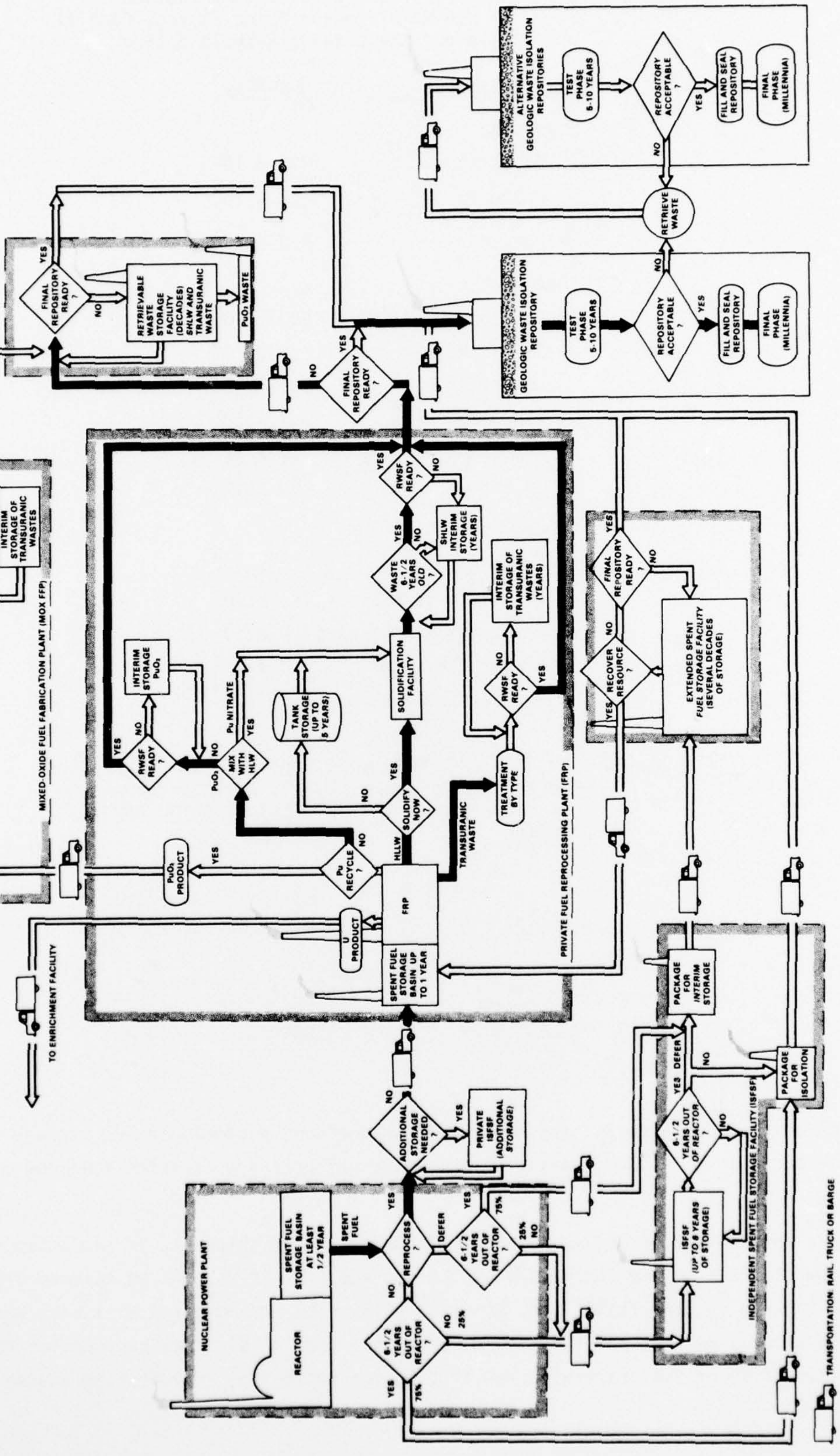

FIGURE 10.6-2. Flow of Spent Fuel and Wastes (Outlined in Black) in the Uranium Recycle Option with Plutonium Stored as Oxide

TABLE 10.6-1. Resources Committed to Construction of 17 200-MT Plutonium Oxide Storage Facilities for the Uranium Recycle Option

Resource	Quantity
Land, ha	
Facilities	2.2×10^2
Property	1.7×10^4
Water, m^3	1.3×10^5
Materials	
Concrete, m^3	8.0×10^5
Steel, MT	1.9×10^5
Copper, MT	2.7×10^3
Zinc, MT	7.7×10^2
Aluminum, m^3	6.0×10^2
Lumber, m^3	4.3×10^4
Energy	
Propane, m^3	1.1×10^4
Diesel fuel, m^3	1.1×10^5
Gasoline, m^3	7.0×10^4
Electricity, kWh	5.3×10^7
Manpower, man-yr	4.6×10^4

TABLE 10.6-2. Materials Committed to Construction of Shipping Casks Used to Transport Plutonium Oxide in the Uranium Recycle with Plutonium Stored as Oxide Option

Material	One Container	Total Required (63 Casks)
Stainless steel (SS), MT	0.5	32
Chromium (in SS), MT	0.09	5.7
Nickel (in SS), MT	0.04	2.5
Lead, MT	0.5	32

Nonradiological aspects of operating an independent plutonium oxide storage facility are given in Table 10.6-3. No significant ecological effects are expected from operation of the facility.

Over the 70-year period ending in 2050, about 11,000 shipments of plutonium oxide will be made from the FRPs to the retrievable waste storage facilities. At an assumed distance of 2400 km between the two facilities, about 53 million km (round trip) will have been traveled. This travel will require about 64,000 m^3 of diesel fuel. This fuel consumption represents an additional 5% of fuel otherwise required to transport fuel reprocessing wastes.

TABLE 10.6-3. Nonradiological Aspects of Operation of an Independent 200-MT Plutonium Oxide Storage Facility

	Annual Rate
Water consumed, m^3	1.6×10^5
Materials	
Oil, m^3	2.3×10^2
Electricity, kWh	2.9×10^7
Heat released to atmosphere, MW	2.1×10^8
Manpower, man-yr	6.1×10^1

In addition to the use of overpacks, shipments of plutonium oxide would be subject to federal packaging requirements,(1) which specify that the inner pressure vessel must not release plutonium when the entire package is subjected to the accident test conditions. No accidental release of radioactive material is postulated for shipments of plutonium oxide.

Injuries and fatalities associated with nonradiological accidents were calculated using an injury rate of 0.44 per million km traveled and a fatality rate of 0.045 per million km traveled. Over the 70-year period ending in 2050, about 53 million km will have been traveled in the transport of plutonium oxide. About 23 injuries and about two fatalities would be expected from this travel.

Doses to the maximum individual and to the population from routine transport of waste plutonium oxide are believed to be without consequence. The dose to the transport work force adds about 2.3×10^3 man-rem to the dose to these workers from transport of other fuel reprocessing wastes. Radiation dose received by the maximum individual, the population along the transport route, and the transport work force are given in Table 10.6-4.

TABLE 10.6-4. Doses from Direct Radiation from Shipment of Waste Plutonium Oxide by Truck

	Year 2000	Peak Year 2010	Through Year 2050
Maximum individual,[a] rem	3.5×10^{-5}	4.5×10^{-5}	1.8×10^{-3}
Population,[b] man-rem	1.3	1.7	6.6×10^1
Transport work force,[c] man-rem	5.3×10^1	6.7×10^1	2.6×10^3

a. Assuming that each shipment passes by the same individual.
b. The annual dose to the population from naturally occurring sources along the transport route would be 9.6×10^3 man-rem.
c. It is assumed that two individuals are assigned per truck; one drives while the other rests.

<u>REFERENCES FOR SECTION 10.6</u>

1. <u>Code of Federal Regulations</u>, Title 10, Part 71, Section 42, Appendix B.

ACRONYMS LIST

ACRONYMS LIST

A-E	architect-engineer
AAPG	American Association of Petroleum Geologists
ACVSF	air-cooled vault storage facility
AEC	Atomic Energy Commission
AECL	Atomic Energy of Canada, Limited
AFR	away from reactor (spent fuel storage)
AGNS	Allied General Nuclear Services
ALARA	as low as reasonably achievable
AMAD	aerodynamic median activity diameter
AP	activation product
API	American Petroleum Institute
APS	atmospheric protection system
BFRSS	Barnwell Fuel Receiving and Storage Station
BIF	bitumen immobilization facility
BPPF	Barnwell Plutonium Product Facility
BTU	British thermal unit
BWR	boiling water reactor
CANDU	Canadian heavy water reactor
CDC	canister decontamination cell (cubicle)
CFR	Code of Federal Regulations
CIF	cement immobilization facility
CRWM	Committee on Radioactive Waste Management
CUP	cask unloading pool
CVCS	chemical and volume control system
CW	canistered waste
CWMS	Generic Environmental Impact Statement on Commercial Radioactive Waste Management, DOE-1559
CWTF	cask weld test facility
DCSF	dry caisson storage facility
DF	decontamination factor
DOE	Department of Energy
DOG	dissolver off-gas
DOP	dioctyphthalate
DOT	Department of Transportation
DTPA	diethylenetriamine pentaacetic acid
ECWS	essential cooling water system
EPC	engineering, procurement, and construction
ER	environmental report
ERDA	Energy Research and Development Administration
ESFS	engineered safety features systems
ESPS	essential spray pond system
FFTF	Fast Flux Test Facility
FP	fission product
FPF	fuel packaging facility
FRP	fuel reprocessing plant
FRPF	fuel residue packaging facility
FRSSF	fuel residue subsurface storage facility
FRVSF	fuel residue vault storage facility
FRW	fuel residue waste
FSA	fuel storage area
FSAR	Final Safety Analysis Report
FSB	fuel storage basin
FTF	fuel transfer facility
FTP	fuel transfer platform
GEIS	Generic Environmental Impact Statement
HCF	hulls compaction facility
HEPA	high-efficiency particulate air (filter)
HEU	highly enriched uranium
HLLW	high-level liquid waste
HLW	high-level waste
HM	heavy metal
HMA	hot maintenance area
HMF	hulls melting facility
HPF	hulls packaging facility
HTD	hulls transfer device
HTGR	high temperature gas-cooled reactor
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
IBC	in-bed combustion
ICPP	Idaho Chemical Processing Plant
IFSF	independent fuel storage facility
IIPSF	independent interim plutonium oxide storage facility

ILLW	intermediate-level liquid waste
ILW	intermediate-level waste
INEL	Idaho National Engineering Laboratory
IPSF	interim plutonium oxide storage facility
ISFS	independent spent fuel storage
ISFSB	independent spent fuel storage basin
ISFSF	independent spent fuel storage facility
LAA	limited access area
LEU	low-enriched uranium
LHD	load-haul-dump
LLW	low-level waste
LN_2	liquid nitrogen
LSA	low specific activity
LWBR	light water breeder reactor
LWR	light water reactor
M&M	men and materials
MFBM	thousand board feet measure
MFRP	General Electric Company's Midwest Fuel Reprocessing Plant
MOX FFP	mixed oxide fuel fabrication plant
MP	mine production
MSRE	molten salt reactor
MTHM	metric ton heavy metal
NAA	normal access area
NAC	Nuclear Assurance Corporation
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NFS	Nuclear Fuel Services
NHLSW	non-high-level solid waste
NLI	National Lead Industries
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
NWTS	National Waste Terminal Storage
ORIGEN	a computer program to calculate isotopic composition of irradiated nuclear fuel
ORNL	Oak Ridge National Laboratory
ONWI	Office of Nuclear Waste Isolation
OWI	Office of Waste Isolation
P-T	partioning and transmutation
PCWS	plant cooling water system
PFRF	packaged fuel receiving facility
PNL	Pacific Northwest Laboratory
POG	process off-gas
PSAR	preliminary safety analysis report
PWR	pressurized water reactor
R&D	research and development
RAA	restricted access area
RBOF	receiving basin for offsite fuel, Savannah River Plant
RCS	reactor coolant system
SCRA	storage cask receiving area
SCSF	surface cask storage facility
SF	spent fuel
SFPF	spent fuel packaging facility
SFRSS	spent fuel receiving and storage station
SFSF	spent fuel storage facility
SHLW	solidified high-level waste
SNM	special nuclear material, i.e., enriched uranium and plutonium
SRP	Savannah River Plant
SSC	sealed storage cask
SSCF	sealed storage cask facility
TBP	tributyl phosphate
TD	theoretical density
TN	Transnuclear Inc.
TRU	transuranic
TSA	transuranic storage area
TWCA	Teledyne Wahchang Albany
U-F	urea-formaldehyde
VE	ventilation exhaust
VOG	vessel off-gas
WBS	water basin storage
WBSF	water basin storage facility
WBSF-PF	water basin storage facility for packaged fuel
WCC	waste calcination cell (cubicle)
WCF	waste calcination facility
WIPP	Waste Isolation Pilot Plant
WTEB	waste tank equipment building
WVC	waste vitrification cell
WVF	waste vitrification facility

MEASUREMENT UNITS AND CONVERSIONS

MEASUREMENT UNITS AND CONVERSIONS

This report preferentially uses the metric system of measurements as defined by the International System of Units (SI). Common English units are often also included in parentheses. Prefixes used with the metric units are defined as follows:

Prefix	Abbreviation	Factor
giga	G	10^9
mega	M	10^6
kilo	k	10^3
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

The following lists identify the symbols used in this report and the factors for converting between the SI and English units.

Symbols for metric units used in this report are:

Symbol	Name
°C[a]	degree Celsius
d[a]	day
g	gram
h (or hr)	hour
ha	hectare
kWh	Kilowatt-hour
J	joule
ℓ	liter
m	meter
min	minute
<u>M</u>	gram-mole/liter
MT	metric ton
MW-hr (or MWh)	megawatt-hour
s (or sec)	second
W	watt

a. Units which are not strictly SI but which are widely used.

Symbols for other units used in this report are:

Symbol	Name
atm	atmospheric pressure
BTU	British thermal unit
Ci	curie
°F	degree Fahrenheit
ft	feet
gal	gallon
in.	inch
lb	pound
MFBM	thousand board feet measure
psi	pounds/square inch
R	roentgen
rem	roentgen equivalent man
yd	yard
yr	year

To convert metric to English, multiply by:

Metric	English	Factor
°C	°F	(°C x 9/5) + 32
cm	inch	0.3937
ha	acre	2.47
kg	lb	2.205
km	mile	0.6214
ℓ	gal	0.2642
m	ft	3.281
m^2	ft^2	10.76
m^3	MFBM	0.424
m^3	ft^3	35.31
m^3	gal	264.2
m^3	yd^3	1.308
MT	ton	0.9070
W	BTU/hr	3.413
W-s/kg-°C	BTU/lb-°F	2.39×10^{-4}
W/m-°C	BTU/hr-ft-°F	0.576

To convert English to metric, multiply by:

English	Metric	Factor
acre	ha	0.405
BTU	W-hr	0.2931
BTU/lb-°F	W-s/kg-°C	4187
BTU/hr-ft-°F	W/m-°C	1.735
°F	°C	(°F-32) x 5/9
ft	m	0.3048
ft^2	m^2	0.0929
ft^3	m^3	0.0283
gal	ℓ	3.785
gal	m^3	3.785×10^{-3}
inches	cm	2.540
lb	kg	0.4536
mile	km	1.609
MFBM	m^3	2.360
ton	MT	1.103
yd^3	m^3	0.7646